Journal of the Forest Products Research Society

PROCEEDINGS OF THE 7TH NATIONAL MEETING, MEMPHIS, TENN., JUNE 15, 16, 17, 1953

R. D. Pauley, K. G. Chesley

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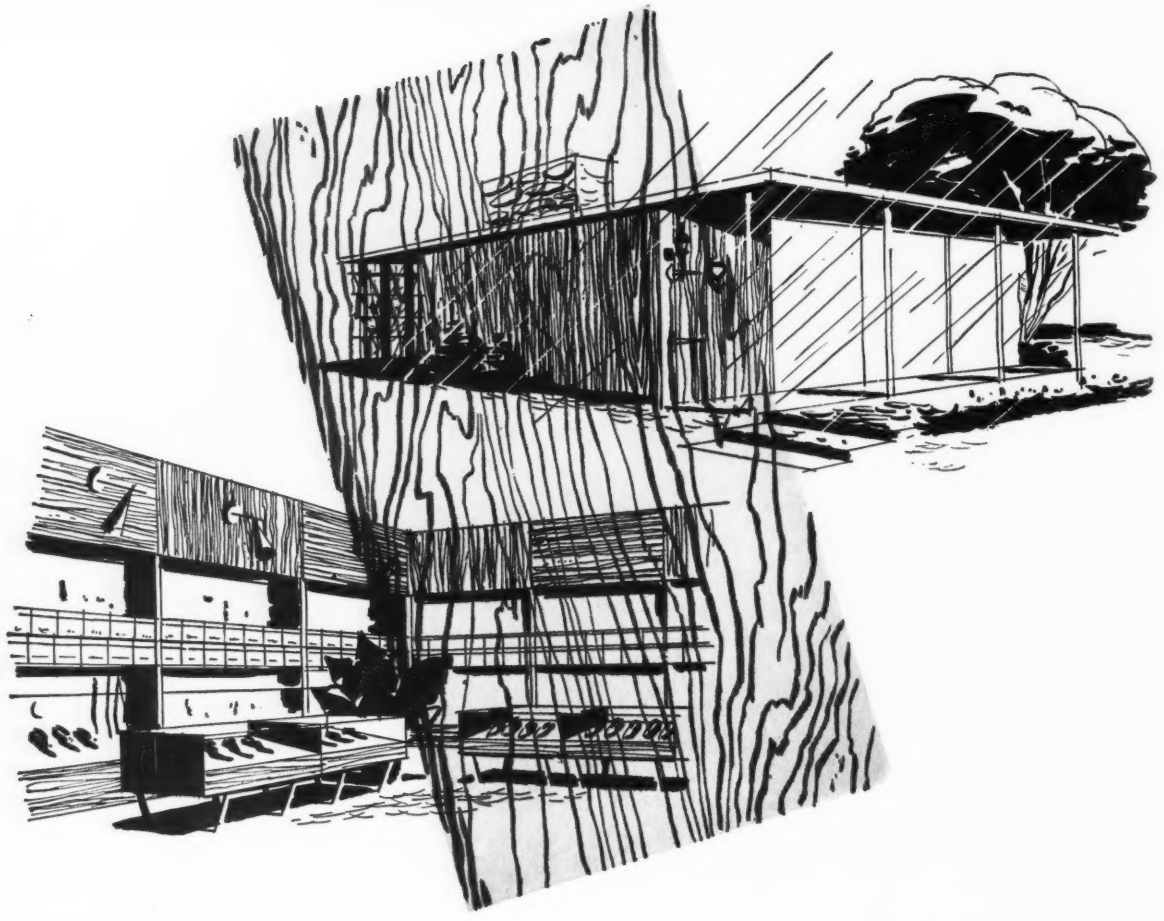

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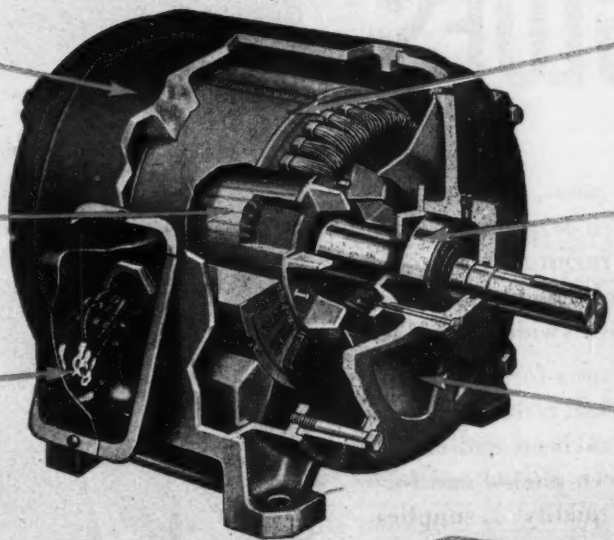

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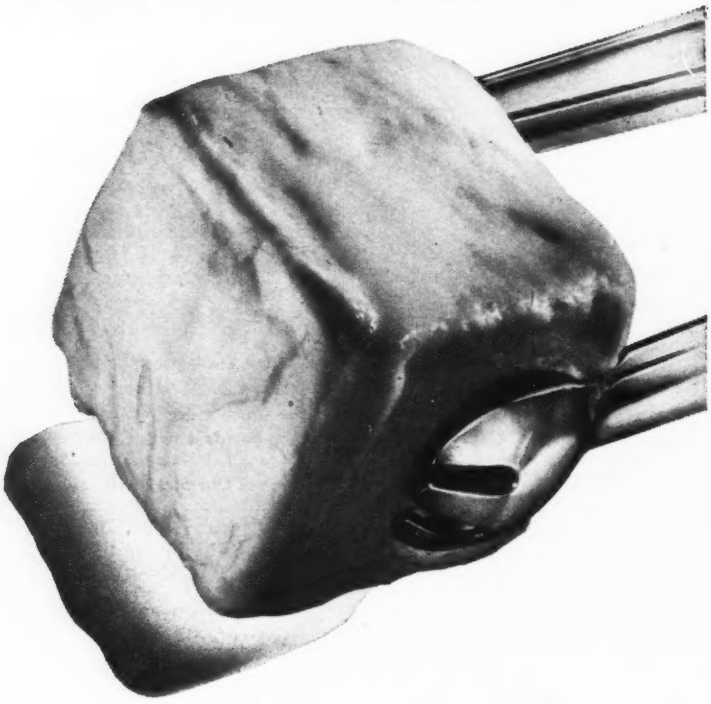

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FPRS News

Merchandising Award Announced

Woodworking Digest, Hitchcock Publishing Co., Wheaton, Ill., has announced the creation of an Award Contest to focus attention on industry companies and associations that are doing outstanding jobs in the merchandising of wood and in wood utilization and in the development of new products that help keep wood in a strong competitive position.

The awards will be made in a number of industry categories. A panel of judges will be chosen from various industry associations and individual leaders. The Awards will be made at the 8th Annual meeting of the Forest Products Research Society at Grand Rapids, Mich., May 5, 6, 7, 1954. Details will be published in the January, 1954, issue of Woodworking Digest and otherwise publicized. Further information may be obtained by writing Woodworking Digest.

This award will compliment the Wood and Wood Products Award given each year for outstanding student papers.

Executive Board to Meet in Madison

The FPRS Executive Board will hold its next meeting at the Society's National Offices at Madison, Wis., on March 1–2, 1954. Chief problems that will receive attention of the Board at that time will be to work out a budget and otherwise review finances for 1954, and to make a thorough going study of the Society's growing publications program and attendant problems.

Marketing Committee Formed

At a recent special meeting in Chicago, it was voted to form a Subject Matter Committee on Marketing. President Robert D. Pauley, who attended the meeting, appointed Phil Creden of Hines Lumber Co., Chicago, to serve as committee chairman until the Annual meeting in May.

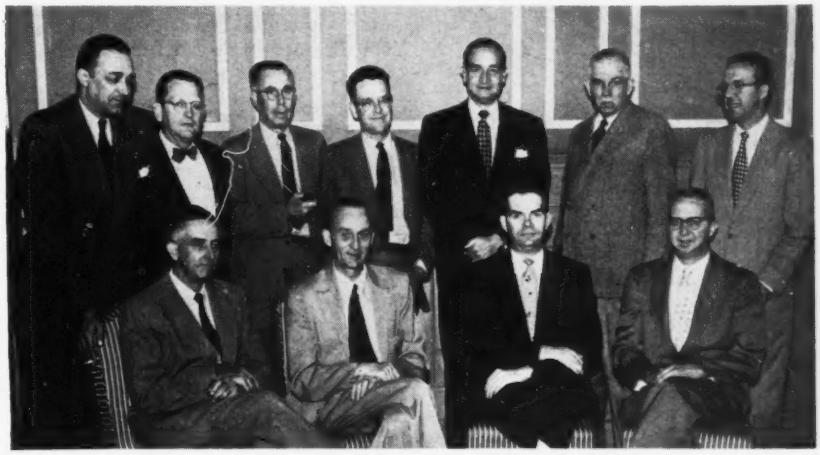
1954 National Meeting

Plan now to attend the 1954 Annual Meeting which will be held May 5, 6 and 7 at Grand Rapids, Mich., at the Pantlind Hotel. In conjunction will be held the "1954 Woodworkers Industry Show", a full-scale machinery and supplier exhibit, with which FPRS is cooperating.

FPRS Officers and Committees

WITH A MEMBERSHIP of over 2600 persons as this Annual issue goes to press, the National work of FPRS is administered by elected Executive Board comprised of five officers and six regional board members. The sectional work is governed by 84 officers and trustees. The various administrative and subject matter committees add another 117 names to the work of the Society.

On this and following pages are listed a majority of the people who are the leaders of this dynamic movement for a strong forest products industry. To each and to their wives FPRS' 2600 members acknowledge a sincere debt of gratitude.



EXECUTIVE BOARD MEMBERS, left to right, seated: Moss B. Christian, L. J. Carr, Robert D. Pauley, and K. G. Chesley. Standing are: W. B. Wilkins, E. S. Harrar, J. Alfred Hall, F. R. Armbruster, W. Jeter Eason, Ray E. Shreck, and Frank J. Rovsek.

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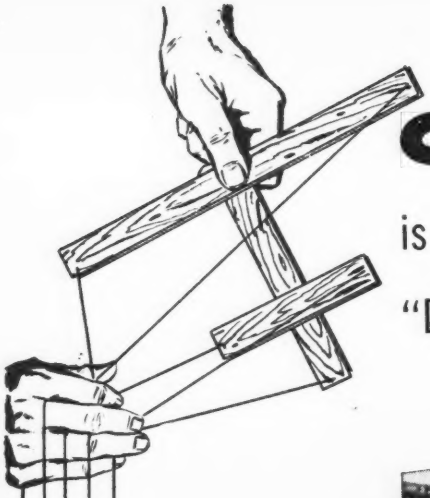

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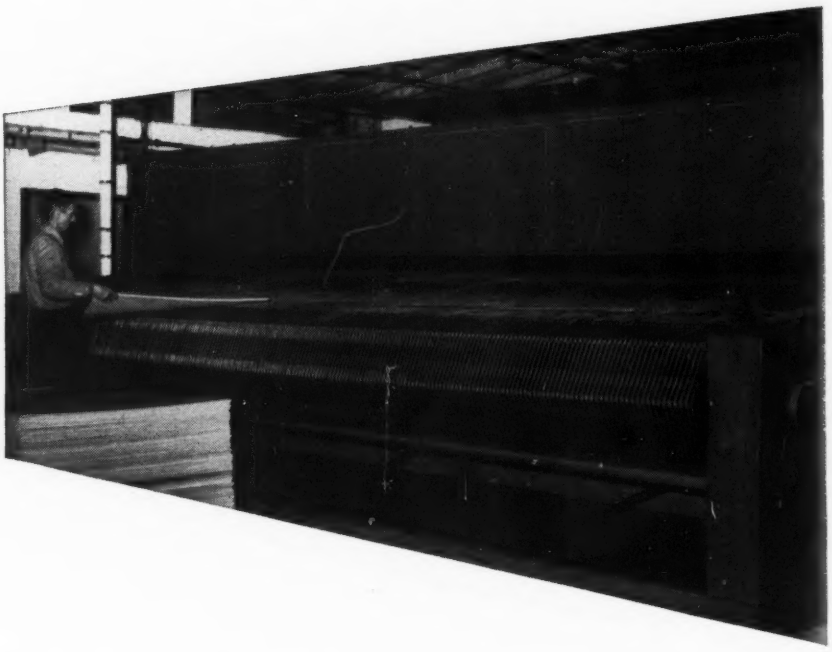

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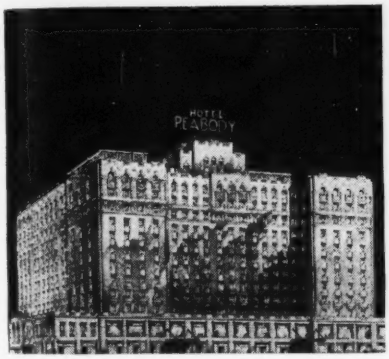
1953 National Annual Meeting

COST CUTTING by means of statistical control, increased production through use of carbide cutting tools, practical gluing of preservative treated wood, and latest furniture finishing techniques are but a few of the briefcase full of ideas that 424 wood industry executives, suppliers, researchers and suppliers took home from the 7th annual meeting of the Forest Products Research Society, held June 15–16–17 at the Peabody Hotel in Mem-



phis, Tenn. Three hundred and eleven members and 113 guests, in addition to 33 ladies, took part in eight technical sessions, a variety of subject matter committee meetings, tours of Memphis area wood products plants and the traditional Society social events.

Executive Board Meets

Preceding the official opening of the three-day meeting, the FPRS Board of Directors met for an all-day session on Sunday, June 14, under the chairmanship of retiring president, Ken G. Chesley, Director of Research, Crossett Lumber Co., Crossett, Ark. The Board reviewed the previous fiscal year and current finances; and authorized setting aside into savings-type securities a small financial reserve for future needs. It reviewed a proposal of the "1954 Woodworkers Industry Show" organization and approved cooperation in arrangements. A full-scale machinery show will be held in conjunction with the FPRS Eighth Annual National Meeting in Grand Rapids May 5, 6, 7, 1952. In other actions affecting the membership the Board voted to authorize additional assistance in the Executive Office, and strengthen review of qualifications and classification of FPRS members.

FPRS "Subject Matter" Committees Meet

Sunday evening the Education Committee, composed of leaders in the field of wood education, met to discuss specific means colleges, universities and industry can employ to further the training of qualified specialists for various branches of the wood industry; and attract promising students into wood technology schools. Prominent educators from virtually every such university in the U. S. and Canada were represented, under the direction of the Committee Chairman, Dr. Robert Wellwood, University of British Columbia, at Vancouver.

Monday morning the meeting officially opened with formal registration, $6 members, $10 non-members, and the annual business meeting of the Society (see page 7). Reports of the Executive Secretary, Audit, Membership, Publications, Resolutions and Subject Matter Committees were read. Several constitutional amendments clarifying dues and student services were adopted. A Tellers' Committee was appointed. A moment of silent meditation for deceased members was observed.

Throughout the day on Monday various FPRS subject matter committees met to discuss organization and projected committee work. These included committees on Glues and Gluing, Wood Drying, Quality Control, Logging and Milling, Wood Machining, Packaging, Composition Board, Chemical Utilization, Wood Preservation and Wood Finishing. Committees on Student Services and National Membership also met, as well as the Carbide Standardization Committee of ASME.

Pres. Chesley Opens Technical Sessions

The technical program opened with sessions I and II on Monday afternoon, covering new developments in Quality Control and in Glues and Gluing. Keynote address of the Quality Control session was given by Carl E. Noble, Superintendent, Customer Acceptance Laboratories, Kimberly-Clark Corporation, Neenah, Wis. The title was "Statistical methods and the modern quality control program". Mr. Noble reviewed the philosophy of statistical quality control and pointed out how it can be used to maintain product characteristics on which continuing customer acceptance is based.

John J. Lawlor, Quality Control Dept., National Store Fixtures, Inc., Odenton, Md., gave a paper entitled, "An application of statistical methods to the Thickness Control of Lumber Core Panels". Said Mr. Lawlor, "The real value of the control chart lies in its sensitive reaction to the presence of assignable causes of variation. As soon as a point goes out of control limits, a prompt hunting for the cause can bring about its discovery and correction."

"Quality control in furniture manufacturing" was discussed by Richard C. Calahan, Assistant Superintendent, Inspection Department, The Singer Manufacturing Company, South Bend, Ind. Mr. Calahan gave a number of practical hints on obtaining within-plant acceptance and cooperation in instituting a quality control program.

Robert H. Ripley, Head, Quality Testing Operations, Douglas Fir Plywood Association Laboratory, Tacoma, Wash. presented "Effective quality control on end product", and discussed the success of his association in maintaining quality standards in the numerous separately owned and operated plants.

"Some applications of statistical quality control to the drying of lumber" was the title of a paper presented by Willard E. Pratt, head, technical division, California Redwood Association, San Francisco, California. Mr. Pratt pointed out how standard quality control measures make it possible to quickly detect moisture variations in lumber that are due not to the normal variations of production but to unwanted and correctable causes.

The quality control program and ensuing discussion was arranged and directed by Charles Latimer, Nickey Brothers, Inc., Memphis, Tenn.

(Continued on page 233)

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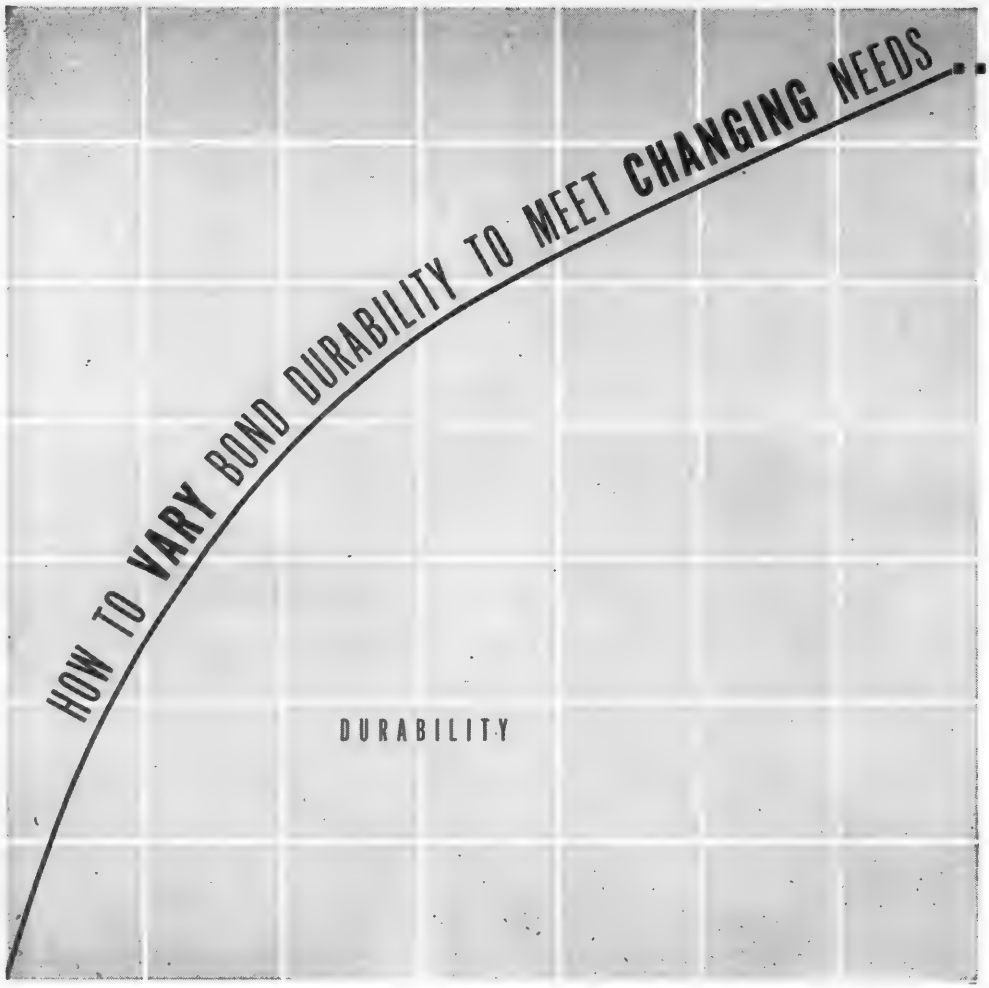

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Journal of the Forest Products Research Society

RESEARCH ★ DEVELOPMENT ★ PRODUCTION ★ UTILIZATION ★ DISTRIBUTION

Vol. III, No. 5 December, 1953

Research and the Whole Wood Pile[1]

HONORABLE REPRESENTATIVE HARRIS ELLSWORTH

Member of Congress, State of Oregon

SINCE I HAVE BEEN in Memphis and have had an opportunity to observe this National Convention of the Forest Products Research Society, it has become quite apparent to me that you have achieved something that is of importance to the whole field of forest products industry. I am referring to the unity of interest in the general field of forest products research as exemplified by the fact that you are drawn from all segments of the vastly differentiated wood industry and that your program gathers together matters of interest in many specialized fields into an organic whole.

There was a time when almost all of the product of the forest went to lumber and fuel, but that is no longer true. Pulp and paper products, for example, are taking about as much wood as was indicated in the total lumber production of the country 20 years ago and the steady increase in pulp and paper consumption indicates that there is no visible limit to the requirements of our people in this field.

The relative newcomers in the field of fiber products—hardboards, softboards, and their various relatives—are increasing in importance at the same time that plywood continues to increase in demand.

This proves to me the validity of the basic concept of the Forest Products Research Society, that the unification of research effort in forest products is bound to be followed by closer unification and integration of all the multiple units of industry that depend upon wood products.

Long ago I became thoroughly convinced that the way to have and perpetuate productive forests was to learn to use the forests wisely and well. I also learned that a single-product industry, lumber for example, or plywood, or pulp and paper, not integrated with other industries, was likely to prove destructive of forest values. It has seemed to me that we do not take advantage of all the manufacturing techniques that we know in order to do a much better job of integration of forest industries.

It seems to me also that there is too much of a lag between the time research results are obtained in forest products and the time they are put to work. For example, where there are perhaps only a half dozen steel companies that by themselves can use extensive research programs, sales programs, and developmental programs, there are, on the other hand, 50,000 or more sawmills or producers of basic wood products. There is a vast difference between conducting research in that field and conducting research in steel or aluminum or petroleum, whose units are vast, well financed, and well organized.

In 1951, for instance, while the lumber industry was investing the meager total of $810,000—3/100 of one per cent of its gross product value—in product research, here is what its competitive industries were doing:

Chemicals put in $204,170,000—or 2.5% of its gross products—into research.

Fabricated metals allocated $38,404,000—or 0.9%—in product development. In addition, primary metals invested $34,415,000—or 0.4%.

[1] Highlights from official luncheon talk of Rep. Ellsworth.

The forest products industries have done tremendously well with glued and laminated wood and plywood manufacturing since the chemical industry made the waterproof, durable, synthetic resin glues available.

Suppose now that from a layman's point of view we run over together the future of wood as we see it. In the first place, let's think about wood as a raw material for the engineer who is going to build or manufacture something out of pieces of wood as wood. What have we done, and what do we need to do? Through the efforts of a lot of research men, we know that wood has finally reached a position of some prestige as an engineering material on the basis of predictable strength properties. Yet there is still, I am told, an awful lot of wood wasted by overdesign. We know that we have made excellent progress in recent years in our ability to fabricate designed members—arches, trusses, beams, and so on—from wood in such ways that their load-bearing capacity and resistance to stresses are pretty accurately predictable.

There are some other tasks that must be done before we can do a really good job in forest management. We must be able to sell all the grades of lumber that come as a product of the cut, and we must be able to sell them at a profit.

But there is more. I have seen recently some interesting combinations of veneer and paper stock put together with glue that develop extremely important properties from the standpoint of strength and resistance to the give-and-take of moisture.

One of the obstacles to the fullest possible growth in the laminating field is that we still do not have adequate inspection methods to determine whether we have done a good job of gluing or not; to know without breaking something apart whether you have stuck it together well.

The basic property of the wood fiber that still plagues all branches of the forest products industries is its propensity to take on and give off moisture, and shrink and swell. I can dream about a piece of wood that is fireproof, decay-proof, shrinkproof, and cheap, and possibly, at the same time, made out of stuff that we now burn up or throw away.

We are not paying enough attention to the ordinary processing of wood. There must be opportunities for improvement in manufacturing and refinement that should yield to strong research effort. Fundamentally, a sawmill runs just about the same way it did 40 years ago. In the woodworking plant, there are a lot of high-speed and high-production shaping machines, but they don't do anything much differently than the old furniture factory did it a half century back. We are using a lot of new combinations of materials that are really challenging our engineers. Therein I see some hope. If we can get away from the idea that we must use lumber or paper or veneer by itself and begin to think in terms of putting all kinds of wood products together, to make the most useful goods, I think we shall have made a very important step forward.

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LANSDALE, PA. KITCHENER, ONT.

TECHNICAL SESSION I—Mon., June 15, 1953, 2:00 P. M.

Subject: Quality Control

Chairman: Charles Latimer

Recorder: James Bethel

Statistical Methods and the Modern Quality Control Program

CARL E. NOBLE

Superintendent, Customer Acceptance Laboratories, Kimberly-Clark Corporation, Neenah, Wisconsin

Demands for greater production and better quality compel the Forest Products Industries to develop more effective quality control programs. Statistical concepts and methods supply valuable and often necessary aids in the establishment of such programs. The modern quality control program should include (a) significant and reliable quantitative measures of product quality, (b) realistic specifications, and (c) systems for controlling and improving quality from the raw materials to the customer's use of the product.

THE FOREST PRODUCTS INDUSTRIES have long possessed systems for controlling quality and many of these systems have served well. It is not surprising, therefore, to hear an executive in one of these industries ask, "How can statistical methods improve our present systems of quality control? Why are these systems inadequate?" B. E. Sooy, Gardner Board and Carton Company, gives a partial answer to these questions when he says that we must obtain greater production to lessen cost and better quality to meet customer requirements. The papermaker is finding it difficult to produce paper for the present day high speed presses with quality control systems developed in the 1920 era. Statistical quality control offers such systems a much needed lift. It demands that the procedures of sampling and measuring the product and analyzing, interpretating, and reporting quality data be reevaluated. This paper describes the various aspects of a "modern" quality control program and the role of statistical methods in the development of this program. It is fitting to begin the discussion with a brief explanation of the nature of statistical methods.

Nature of Statistical Methods

Statistical methods are applicable in processes yielding measurements subject to variation, and such processes are everywhere in research and production. Variation not only occurs but is expected. Statistical methods involve a study of variation. The pattern of variation for many processes can be adequately characterized with examples in games of chance. The basis of much of the statistical methodology lies behind such patterns of variations. Consider a game in which your opponent tosses twelve dice. On the average two aces would be expected each time the twelve dice are thrown. Thus, a fair method of playing this game would call for him to pay you two dollars before the toss and in return to receive one dollar from you for each ace he tosses. Variation in the number of aces is expected. However, what would you do if your opponent throws four aces and wins two dollars from you? Have you been cheated? What if he throws five, six, or seven aces? When should you become concerned with this process? When should action be taken? Too often your decision depends entirely upon subjective judgment, your physical and financial condition, and not upon a knowledge of the dice tossing process and the probabilities associated with it.

Probability theory gives the exact probability of obtaining four, five, or any number of aces when the dice throwing process is unbiased. Figure I depicts the probabilities of various numbers of aces turning up when twelve dice are tossed in an unbiased operation. This chart shows the probability to be 0.125 that four or more aces will appear. Hence, when one is playing this game he should expect four aces occasionally. However, seven or more aces occur by chance only one time in a thousand tosses, and such an event deserves action. A decision to thoroughly investigate the dice throwing process whenever your opponent tosses seven or more aces seems wise.

The manufacturers of forest products are continuously faced with making decisions on processes which are similar to those in dice tossing. If the finish of a sample of paper selected from a lot is one point low, is the finish for the entire lot off standard? What is the probability of this sample of paper measuring one point low even though the entire lot is standard? There is variation in finish throughout a lot of paper the same as there is variation in the number of aces obtained in the dice tossing process. Should the furniture manufacturer be alarmed with his percentage of waste in a certain operation yesterday because it increased from the standard of 8 percent to 12 percent? This manufacturer cannot answer the question intelligently unless he has some indication of the probability of securing a waste figure of 12 percent when the factors contributing to waste are normal. A principle function of statistical methods is to provide the probabilities associated with the various waste percentages. With this information there can be set realistic control

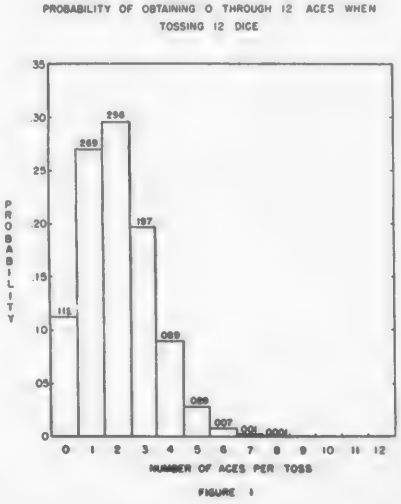

FIGURE 1

ABOUT THE AUTHOR: NOBLE, CARL E. Received Ph.D. from the State University of Iowa. During World War II served as director of a proving ground testing proximity fuses. Joined Kimberly-Clark in 1946. Taught short course in Quality Control by Statistical Methods at Iowa and a course in Statistics at the Institute of Paper Chemistry, Appleton, Wisconsin. Member: American Statistical Association, Institute of Mathematical Statistics, Fellow in the American Society for Quality Control.

limits within which the waste percentages can be expected to vary even though the process is normal. Since the probability is small that one of these percentages will fall outside the control limits from chance causes alone, it is assumed that the process is not normal when such an event occurs and action is taken to bring the process back to normal.

Measurement

The description of the nature of statistical methods lays the foundation for the development of a statistical quality control program. A sound quality control program demands first that quality be measured quantitatively. In the Forest Products Industries there are ever so many important quality characteristics for which no quantitative measurements are available. Quality is still judged entirely upon a qualitative basis for these characteristics with no agreement regarding what is satisfactory quality. Its insistence upon quantitative measurements is probably one of the greatest contributions that statistical quality control can make to industry. S.Q.C. provides attributes and rank measurements and the jury panel approach where the usual variables type measurements are not applicable. For example, with attribute measurements there are established photographs, specimens of the product, and written standards which serve as divisions between satisfactory and unsatisfactory quality. These points of division are set and agreed to by the personnel having the know-how and information necessary for establishing reliable standards.

Specifications

The next step in the development of the quality control program brings realistic specifications which take into account the customer needs, the capabilities of the manufacturing process, and costs.

A. **The Product Must Meet the Customer's Needs.** During the war Army personnel were provided with rations which passed every chemical and biological test. In spite of these test results (which were not known or cared about by the men) some of these rations were universally rejected by the soldiers (1). The significant taste specifications were overlooked.

The practice of including specifications of little importance to the customer can be as costly sometimes as the omission of significant specifications. There are examples where the specifications on a paper product call for (say) bursting strength far beyond that required for the end use of the paper. The maintenance of high bursting strength not only adds cost but frequently reduces the ability of the paper to meet some of its other specifications such as those for printing. Specifications should meet, as nearly as possible, the true needs of the customer.

B. **Specifications Must be Consistent with Process Capabilities.** A certain packaged paper product had a length specification of 9 inches $\pm \frac{1}{16}$ inch. After many customer complaints, the process and product were investigated to determine if these specifications were *too wide*. The measurement of series of ten consecutive items produced in less than ten seconds revealed that even over such a short production interval the variation in lengths was such that the process required specifications near 9 inches $\pm$ $\frac{1}{8}$ inch, twice as wide as the established specifications.

This brought to light the fact that the operators had been forced to ignore these narrow specifications in order to get out production and actually were operating without any specifications. The specifications were then widened to 9 inches $\pm$ $\frac{1}{8}$ inch and a control system set up to insure that these reasonable specifications be met. It should be added that these new specifications were satisfactory to the customer. Not one customer complaint has been received on the length of this item in over three years.

C. **Finally,** the necessity of setting specifications in such a manner that the product can be manufactured at a competitive cost needs no elaboration here.

Statistical quality control does not replace judgment. It promotes a program which uses the best available judgment based upon objective facts to establish quality control in a company. This is in evidence in the formulation of specifications. Practical expediency dictates modifications of specifications from time to time. However, these modifications should be made by individuals who have the facts concerning process capabilities and the end use requirements of the product, and not by the operator whose primary interest may lie only in an improvement of his production efficiency.

Complete specifications should state clearly (a) the amount of product to include in a lot, (b) the method of selecting the sample from the lot, (c) the procedures for testing the specimens in the sample, (d) the statistics (such as the arithmetic mean) to calculate from the test data, (e) the conformance limits for the statistics, and (f) the action to take on the lots when the statistics fail to meet their conformance limits. The teeth are taken out of specifications too frequently by failure to explicitly set forth the action to take upon non-conforming lots. A statement of action on non-conforming lots places specifications on a businesslike basis. This phase of specifications motivates the Manufacturing Department to establish systems of raw materials inspection and process quality control and to take other steps to insure that the finished product meets the specifications.

Raw Material Inspection

A good quality control system measures and aids in the control of quality from the raw materials to the finished product. A system of raw material inspection is rather easy to establish if sound specifications are available. The literature is filled with sampling inspection tables for performing this function (2–5). However, the raw material inspection problem is often clouded by the fact that the customer is unable to tell the supplier what is wrong with his product in language which the supplier understands. There is needed the quantitative measure of quality.

A paper converting mill had difficulty with the carton used to package one of its products. The cartons failed to run consistently in the packaging machine. The mill complained that these cartons did not open properly, break at a scored line, or seal. Such complaints had limited meaning to the carton manufacturer. After repeated complaints failed to improve the quality of the cartons, the mill initiated a program in which all the bench tests that could have any conceivable influence upon the runnability of the cartons were made on each lot of cartons received. In fact, new bench tests were developed. The manner in which the cartons in each lot ran on the packaging machine was correlated with each of the bench tests. A number of the bench tests were found to correlate well with the runnability of the cartons on the packaging machines and to supply data from which the runnability of the cartons could be predicted. The carton manufacturer was shown these tests and given specifications within which the test data must conform in order for the cartons to run satisfactorily. The data from these significant tests formed the basis for modifications in the manufacturer's production processes and subsequently for the control of these processes. The quality began improving and within one year after the manufacturer was given these tests, the number of delays due to poor car-

ton runnability was cut 75 percent. It may be true that the customer is right by definition, yet he has much to gain with a cooperative attitude toward the supplier in the common quality improvement problems.

Process Control

Statistical quality control's most outstanding contribution to industry is probably in the field of process control. It stresses the philosophy that quality should be built into a product. To insure quality by screening the defective items from the finished product is too costly. In fact, this procedure is difficult to apply with many products such as rolls of paper.

The work horse of statistical quality control is the control chart. It has helped control paper quality from the trees to the finished paper. Printers are using this chart as the basis for inspecting incoming paper for ream count, basis weight, moisture content, and many other characteristics as well as to control such factors as paper waste, ink consumption, printing quality, and press delays in their own operations. The control chart is aiding the plywood manufacturer in improving both the level and uniformity of quality in many of his operations.

An example of the application of a control chart to improve basis weight uniformity shows the benefits obtainable with this chart. Before the control chart was introduced the machine tenders were sometimes making as many as 20 adjustments during a 24-hour period in order to maintain what they considered standard basis weight. The decision to make an adjustment usually depended upon the basis weight measurements of a sample taken at the end of a reel. If the basis weight measurements for this sample averaged 0.5 of a pound above standard, the basis weight was often lowered to bring it back to standard. The adjustment was made without full realization of the variation in the basis weight measurements. The machine tender needed an answer to the question: "How much variation in basis weight in the sample must be expected even though the average basis weight within the entire reel is standard?" What is the probability of the basis weight in the sample averaging 0.5 pounds high when the basis weight in the reel is standard? This information greatly helps the machine tender produce more uniform quality. In general, he has been over-correcting his process. He has raised and lowered his machine basis weight as a result of sample averages which were within the normal variation of his process. It must be remembered that each of these unnecessary adjustments merely enlarges the variability in the basis weight of the paper.

In face of this background a control chart was set up to aid the machine tenders in controlling basis weight. The machine tenders were instructed to make adjustments in basis weight only when the sample average or range fell outside its control limits. These control limits were proved satisfactory before such instructions were issued. Since the establishment of this control chart system, it has not been uncommon for the paper machines to operate for 24 hours without a basis weight adjustment. The basis weight now varies approximately one-half what it did when over-adjustments by machine tenders greatly inflated the basis weight variability. Industry is filled with examples of over-control by operators. Much of this over-control is forced by narrow specifications which fail to allow for the inherent, uncontrollable, chance variation existing in the manufacturing operation.

Experimental Design

A quality control program can hardly be considered complete unless provisions are made to handle such problems as those of bringing the out-of-control process back to normal and meeting the often occurring situation in which the process capabilities demand specifications unsuitable to customer needs. The solution of these problems and others like them are greatly facilitated by such statistical tools as the "t" test, x^2 test, correlation theory, analysis of variance, and the control chart. These tools provide the basis for designing experiments in order to obtain maximum information at minimum cost.

Statistical methods have much to offer technical personnel in research and development. As a matter of fact they are stymied in many of their experiments without techniques for separating such factors as interactions between cause systems and for studying the effects of many variables changing simultaneously in the more complicated processes. The reader is encouraged to consult the literature (6–10) for further details.

Finished Product Inspection

The statistical quality control program attempts to control the manufacturing operation at each of its critical points in such a way that the finished product will be satisfactory. Even with a rather complete in-process control system it has been found advisable to set up an agency independent of the Manufacturing Department to measure the degree to which the finished product satisfies the customer's requirements. This independent agency (sometimes called a Customer Acceptance Laboratory or C.A.L.) serves as a representative of the customer within the company. Its principal function is to insure that the company's product is suitable for the customer's needs. To carry out this function, C.A.L.:

1. Samples lots of the finished product as they are ready for shipment to the customer.
2. Measures only those quality characteristics which predict the product's ability to satisfy the customer requirements.
3. Is concerned only with those quality deviations affecting the ability of the product to meet these requirements.
4. Reports its quality results directly to top management.

C.A.L. spends much time in the study of such factors as customer complaints in order to determine those quality characteristics of importance to the customer and the extent of uniformity which must be maintained in these quality characteristics. An all-important function of this agency is the development of tests capable of predicting customer experience with the product. The development of such tests has done much to guard against the shipment of unsatisfactory material and has led to many process improvements.

The ability of the paper to print is measured by running it through a printing press. The printed specimens are compared against carefully selected standards and graded as satisfactory or defective of a minor, major, or critical degree. These classifications are set up in such a manner that the customer can tolerate only a small percentage of major defects and no critical defects. The other quality characteristics of customer significance are also classified in the minor, major, and critical categories. If the G. E. brightness of a certain sheet is more than one, two, or three points from standard, the sheet is classified as a minor, major, or critical defect respectively. This system is formulated to promote product uniformity. An unusually high brightness sheet in a sample is considered as undesirable as a sheet of low brightness. The emphasis is placed upon the quality of the individual sheets, with each sheet classified separately. A high reading does not compensate for a low one even though the average of the two may be near standard. The customer is not interested in the average brightness level of the paper produced during a day. He is concerned with the brightness of the paper *he* receives

(Continued on page 209)

An Application of Statistical Methods to the Thickness Control of Lumber Core Panels

JOHN J. LAWLOR

Quality Control Dept., National Store Fixture Co., Inc., Odenton, Maryland

Explanation is given of use of statistical control methods to maintain panel thicknesses within normal variations.

THE 3-PLY LUMBER CORES under discussion are used in the fabrication of table tops surfaced with Nevamar High Pressure Laminates. The thickness control of these cores is essential in order to insure proper matching of the leaf and top thickness in the final table top assembly; to reduce the labor cost involved in the application of T-edging and to control the amount of resanded or rejected panels incurred at the sanding operation.

Collection of Data and the Establishment of Trial Limits

Upon the decision to use statistical quality control techniques as an aid in controlling the thickness variable, the first step involved was the collection of measurement data. This was begun at the sander, where the cores are sanded to their final dimension. Thickness measurements were made with a micrometer. Four readings were made on each panel and a total of five panels, taken in succession, were sampled approximately once every hour.

The average thickness ($\bar{\bar{X}}$) of each subgroup, which is plotted on the following charts as a single point, is the average of the five panel averages. The range ($\bar{R}$) of each subgroup is the difference between the highest and lowest figure of the five panel averages. A sample subgroup reading is illustrated in Figure 1. After a total of 23 such subgroups were secured, trial control limits were calculated and the chart for variables ($\bar{\bar{X}}$ and $\bar{R}$ Chart) shown in Figure 2 was plotted. The center horizontal line shown on the $\bar{\bar{X}}$ and $\bar{R}$ charts represents the average for the subgroup measurements, and the remaining lines, the upper and lower control limits of three standard deviations of the subgroup. At the time the chart was prepared, the nominal desired thickness of the cores was ¾ (.750) inches.

The use of the control chart rests on the provable assumption that a normal variation pattern is present in all production processes. This pattern

					$\bar{X}$
Panel 1	.750	.750	.751	.745	.749
Panel 2	.752	.749	.749	.744	.748
Panel 3	.750	.750	.743	.751	.748
Panel 4	.755	.750	.749	.747	.750
Panel 5	.749	.739	.750	.746	.746

Fig. 1—Ex. of hourly sanding measurements on 5 panels used as a subgroup. N = 5; Mean ($\bar{\bar{X}}$) = .748"; Range ($\bar{R}$) = .004".

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can be stabilized, but variation within it is inevitable.[1] Whenever variation occurs without this stable pattern, assignable causes of variation are present which may be discovered and corrected. The value of the control chart, therefore, lies in its ability to separate out the assignable causes of quality variation.

The area within the control limits illustrated in Figure 2 represents the amount of variation resulting from stable chance causes, which can be considered normal for this sanding operation. Thus, the heterogenous nature of wood, the normal variation of the sanding machine, and other factors inherent to the process at the time the readings were made, will result in a natural tolerance of ± .004" for panel averages of sample size N = 5.

Examination of the control chart revealed a number of interesting facts. (1) The points falling beyond the upper and lower control limits indicate that the process is out of control, and, therefore, there are assignable causes of excess variation present in the operation which it should be possible to identify and correct.

(2) A study of the point grouping found in the $\bar{\bar{X}}$ chart revealed that while the average thickness variation within a single production run was not always excessive, the variation in average thickness between successive production runs was. For example, the data for the subgroups numbered 15 to 22 was secured from a single production run. The variation between these readings was fairly uniform, even though the average thickness was approximately $\frac{1}{32}$" less than the aimed-for thickness of ¾"; with the subgroups 36 to 41, the average readings were on the high side. These groupings suggest the possibility of non-uniform machine set-up between production runs or a variance in the overall core makeup between such runs.

(3) The chart reveals that the average ($\bar{\bar{X}}$) thickness of the cores is .740 inches, rather than the target value of .750 inches.

Upon the determination of the above information, a search was made for the assignable causes of excess variation in the process. Three major factors were found to be influencing the uniformity of the dimension.

A. Variations in veneer thickness and quality.

[1] Grant, E. L., 1946, Statistical Quality Control. McGraw-Hill, New York.

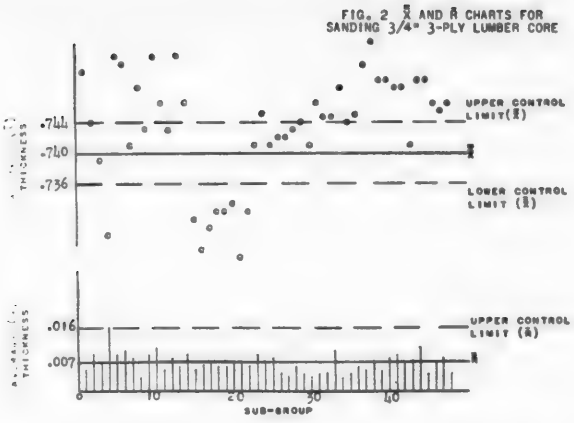

FIG. 2 $\bar{\bar{X}}$ AND $\bar{R}$ CHARTS FOR SANDING 3/4" 3-PLY LUMBER CORE

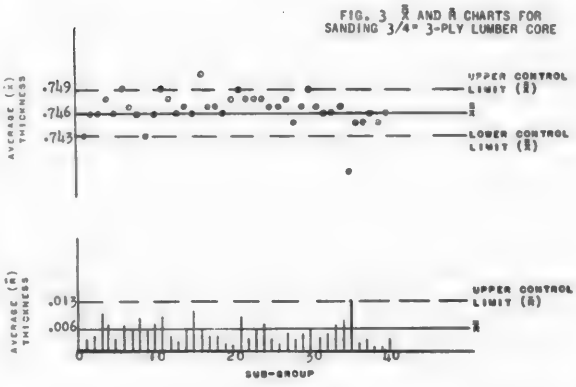

FIG. 3 $\bar{\bar{X}}$ AND $\bar{R}$ CHARTS FOR SANDING 3/4" 3-PLY LUMBER CORE

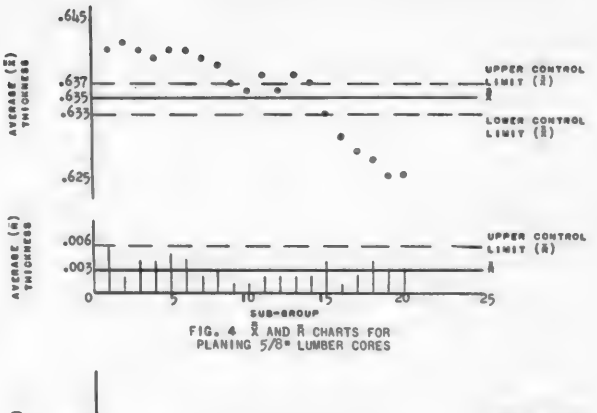

FIG. 4 $\bar{\bar{X}}$ AND $\bar{R}$ CHARTS FOR PLANING 5/8" LUMBER CORES

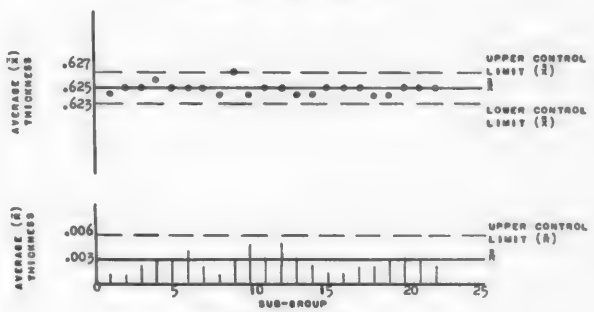

FIG.5 $\bar{\bar{X}}$ AND $\bar{R}$ CHARTS FOR PLANING 5/8" LUMBER CORES

B. Variations in thickness of lumber cores.

C. Setting of sanding machines between various production runs.

Veneer Quality Affecting Thickness Control

A study of veneer quality was being made at this time in relation to another problem. The information available from inspection data already secured revealed a number of factors contributing to excess thickness variation of 3-ply lumber cores.

1. There was a significant difference in the average thickness of veneer being obtained from different outside sources who were supposedly supplying the same nominal thickness. The average sanding machine used in the woodworking industry is not built to hold close tolerances. Because of its flexible rubber bed, the uniformity of final panel thickness depends, to a great extent, on the uniformity of the panels before sanding. Therefore, everything else being equal, the greater the veneer thickness variation, the greater the 3-ply core thickness variation.
2. The veneer species used in the core makeup varied from gum and poplar to maple and sycamore. The difference in hardness and density of these species thus could result in thickness variations at the sander.
3. The smoothness or tightness of the veneer cut was such that excessive resanding was necessary at the sander to obtain smooth faces. While this was a factor in the overall problem, it should be mentioned there that resanded panels were not used in sampling for the $\bar{\bar{X}}$ and $\bar{R}$ charts.
4. A considerable amount of the veneer used was made up of pieced stock with varying thickness occurring between pieces.

As a result of these findings, veneer standards were revised and definite specifications, corresponding to our particular requirements, were drawn. To insure conformity to these specifications, inspection procedures for all incoming veneer were set up and maintained.

Control of Lumber Core Thickness

The lumber cores used in the 3-ply panels were surfaced on a modern double-head Whitney planer, capable of holding close tolerances. In order to secure information on the thickness variation being obtained at this operation, $\bar{\bar{X}}$ and R data was collected and the control chart shown in Figure 4 was drawn. Upon examination of these charts, a lack of control was revealed by points falling outside the control limits on the $\bar{\bar{X}}$ charts. It was also found that an average thickness of .635 inches was being obtained, rather than the aimed-for thickness of .625 inches (5/8").

The assignable causes of excess variation at the planer were traceable to improper machine setting. The metal guage used to establish machine setup did not lend itself to accurate maintenance of uniform thickness between production runs. In addition, the guage resulted in heavier readings than was desired. A micrometer is now used to determine machine setting for this operation.

A pronounced downward trend of thickness readings is evident in Figure 4. This reflects attempts to bring the planing thickness to the desired level during the time the data was being secured.

It is interesting to note that in the case of the 5/8" setting guage used at the planer, a greater average thickness (.635" rather than .625") was being secured, while the 3/4" guage used at the sander was resulting in thinner panels (.740" rather than .750"). Thus, the overall result was that much more veneer was being removed from the 3-ply core at the sander than was necessary, and for quality reasons, not affecting this discussion, more than was desirable.

Figure 5 shows a control chart placed on the operation after the assignable causes of variation were corrected. All points fall within the trial control limits and the process, for all practical purposes, is in control. It should also be noted that the average range ($\bar{\bar{R}}$) is considerably lower than that shown in Figure 4. This reduced variation within the lumber cores was achieved by a more accurate setting of the planer knives and pressure bar.

Application of the Control Chart at the Sander

Examination of the averages and control limits of Figure 3 will reveal an improvement over those found in the preliminary chart in Figure 2. Efforts made toward stabilizing the operation during the time that readings were being secured were reflected in the average and range values of the subgroups 23 to 48 of the preliminary chart. Therefore, in order to bring the thickness readings closer to the aimed-for average of .750″ and to incorporate the improved values in the new chart (Figure 3), these limits were calculated for the subgroups 23 to 48.

Figure 3 illustrates the thickness control achieved at the sanding operation after the application of a control chart, and the subsequent elimination of assignable causes of variation. The process has been brought into control with a substantial reduction of the thickness variability. During the period covered by this chart, only two points have fallen outside the control limits. One of these was traced to a number of panels cupped in the pressing operation. Despite the fact that the average thickness of the lumber core obtained at the planer was lowered, with the same nominal thickness of veneer, there was still no difficulty in holding to the increased finish 3-ply core thickness.

From the values plotted in Figure 3 and information later collected but not shown here, newer averages and limits were subsequently calculated. This resulted in stabilizing the process at a between-panel subgroup average ($\bar{\bar{\bar{X}}}$) of .748″ ± .003″, and a within-panel subgroup range ($\bar{R}$) of .005″ with the upper control limit of the range at .011″. This control is being maintained without undue difficulty.

Conclusions

The real value of the control chart lies in its sensitive reaction to the presence of assignable causes of variation. As soon as a point goes out of control, a prompt hunting for the cause can bring about its immediate discovery and correction. Thus, inferior materials entering into the process, careless machine setting, worn sanding rolls or misaligned beds can be detected before the trouble becomes acute.

From the experience secured with the use of control charts, it is evident that a seldom mentioned advantage of the chart, aside from the information it provides, is its effect on machine operators. The mere presence of the charts, with their constant indication of the quality level being achieved, results in greater attentiveness on the part of the machine operator toward producing a uniform product. In addition, when proper control is achieved and maintained, the operator can point with pride to his quality picture and he will strive to maintain it.

This discussion has been intended only as a practical case study of the application of statistical methods to process control. However, it should be pointed out that the control chart for variables which was used for this particular operation is only one of the statistical control tools available for use. Whenever control of quality uniformity is desired, whether it is in sampling acceptance of raw materials, such as veneers, plywood, or adhesives; process control of moisture content or dimensions; or fraction defective sampling of finished products, statistical charts offer an excellent tool for achieving this goal.

Discussion

Aubrey E. Wyley (New York State University): What is the relation of the control limits for individual panels based on four measurements to the limits based on five measurements. Could you achieve the objective by using charts with limits based on panels?

Mr. Lawlor: We have used this method in our operation and it has served satisfactorily. Control limits based on individual measurements would have a greater spread.

Charles E. Latimer (Nickey Bros., Inc.): Do you need to measure to 1/1000″ or would measurements made with a rule to 1/64″ be satisfactory?

Mr. Lawlor: We have found that we can hold our accuracy of measurement to 1/1000″, we do not need to go to coarser measurements.

Stephen Preston (University of Michigan): It is apparent that this study was made in an operation involving large cuttings. Is this general method applicable to smaller operations?

Mr. Lawlor: Yes. This is a big item for us, however, the method would be applicable even though the quantity involved would be smaller.

Dr. Noble: There is a general misconception concerning use of statistics on small lots. The thing you are trying to do is control the processes and not the lot. Even when there is only one measurement per day the operation of a chance cause system permits the use of statistical control.

Quality Control In Furniture Manufacturing

RICHARD C. CALAHAN

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The use of statistical quality control techniques appears to offer considerable promise in the control of quality in furniture manufacturing. A ten point program for organizing a quality control program in a furniture plant is outlined. Case histories of applications of several statistical quality control techniques to furniture manufacturing operations show that the techniques can provide the pertinent information needed for effective action in improving quality.

THE FUNDAMENTAL TRENDS of the past half century in American industry have, only in recent years, begun to make their impact fully felt on the furniture industry. The manufacturing of furniture is rapidly and surely changing from a field of skilled artisans to a field of mass production in which art becomes a science, where inter-changeability of parts is essential, and where production methods must be simplified to permit rapid training of help.

Scientific management has long recognized the existence of a need for the inspection function in manufacturing. The rapid trend of furniture manufacturing to the mass production techniques, in a market of customers still imbued with the expectation of the skilled craftsmanship of the Hepplewhites and the Sheratons, will inexorably lead to an ever increasing importance of the inspection function.

Recognizing these basic trends and being confronted with the inevitable quality problems resulting from the trends of the post war era—the great emphasis on production, the rapid turnover of personnel, etc., the author became intrigued by reports of that new and startling management tool known as statistical quality control. These techniques, when declassified by the War Department from their secret classification, were revealed to have been a most potent factor in our highly successful war production efforts. In the span of a few years after the close of World War II, statistical quality control, its roots firmly planted during the war effort, was growing by leaps and bounds and with startling successes being the rule rather than the exception.

A rather comprehensive study of the principles and techniques of statistical quality control,—a study of their seemingly endless successful applications—from control of quality in machining operations on automotive crankshafts to control of food waste in airline operations—and the study of the problems of organization for quality control, convinced the author that the statistical quality control approach held great promise in the furniture manufacturing industry as a means of controlling quality all along the production process.

Our world-wide reputation for quality cabinetwork had, for years, been maintained by reliance on old, dependable, and experienced personnel who, certainly, through the years had merited that reliance. A bay inspection system, in which parts are inspected at the conclusion of each of the three major manufacturing phases, machining and sanding, finishing, and assembly, was and still is, to a large extent, in effect.

The need for control of quality all along the production line rather than at three selected points became crystal clear. To put it bluntly, to discover after twenty machining and sanding operations, that the first operation was

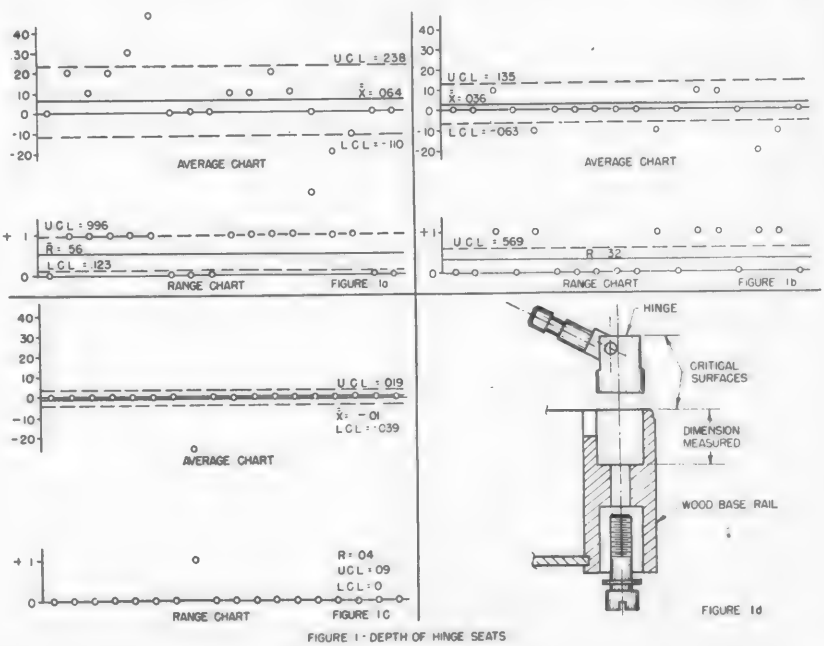


FIGURE 1 - DEPTH OF HINGE SEATS

ABOUT THE AUTHOR: CALAHAN, RICHARD C. Assumed present position February 1948. Supervises entire inspection activity, has specific responsibility for development of statistical quality control program as well as development of other new inspection techniques. Formerly engineer, Bendix Corp., South Bend, Indiana; engineer, Glen L. Martin Co., Baltimore, Md., and engineer for the Singer Company. Joined FPRS in May 1952. Member, committee on quality control. Member, American Society for Quality Control.

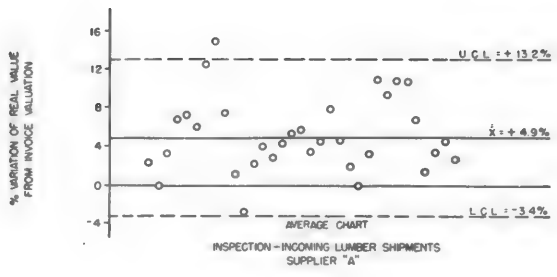


FIGURE 2

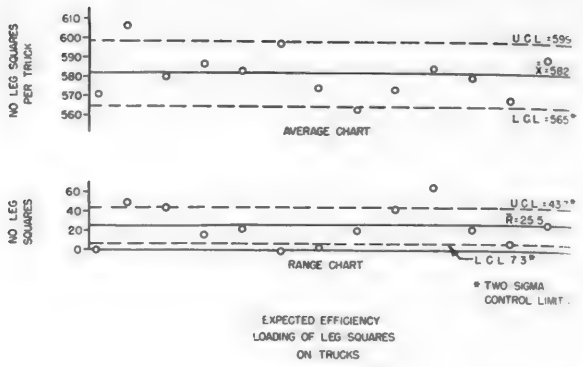


FIGURE 3

defective, is to say the least very costly and highly disconcerting!

Development of a Quality Control Program

From this background, from personal experience in setting up a quality control program and from a study of the experiences and pitfalls of others, a ten point program for organizing and developing a quality control program in a cabinet manufacturing plant is suggested below. It should be strongly emphasized at this point that there is no definite pattern which will fit and be successful in all manufacturing activities. The complexion and character of each business enterprise is different, and to be successful, the quality control program must be completely compatible with that enterprise's way of doing things. That this program or plan of attack appears to be proving successful in our operations is not to say that it is a panacea for all cabinet manufacturers.

1) Define Your Quality Problem: A clear definition of precisely the nature of the quality problem is basic in the establishment of a quality control program. Perhaps the quality problem stems from excessive customer complaints, perhaps the problem lies in producing quality suitable to meet competition or, perhaps, as is the case in question, the quality problem lies in the amount of rework, repair, and scrap involved in achieving the desired end product quality. It is axiomatic to note that if quality of work in process is controlled at the desired levels, there need be little concern for the end product quality.

2) Develop an Overall Plan: In a manufacturing operation of the size the author is concerned with, the development of an overall plan for installation of quality control was a major consideration. Since a complete simultaneous installation was impossible, it remained to develop a logical sequence of installation. Experience had shown that the principal quality problem in the early stages of manufacturing stemmed from defective material. Thus it seemed quite logical to establish first an inspection screening of this incoming material. The use of the statistical quality control technique of acceptance sampling in this connection is discussed later in the paper. At present, this quality control of material is established on rough veneered panels from our other factories, purchased lumber, hardware, and a few other miscellaneous items. At present, veneer is inspected by the Veneer Department and glues and all finishing materials are checked by the Chemical and Physical Testing Laboratories. The author contemplates the use of statistical quality control in these phases, principally to reduce the amount of test work required for quality assurance.

Having established the control of quality of incoming materials, quality control charting techniques are now being applied to the veneering, machining and sanding operations. Because of the scope of the manufacturing operation, this phase of the program may well require several years to establish. Illustrative examples of these process quality controls are discussed later in the paper.

When the control of quality in the machining and sanding phases of the manufacturing operation have been established, the program will be extended to the finishing and assembling stages of production. Of great importance in the establishment of an overall plan for quality control, is the study of ways and means of selling the program to all levels of supervision, and above all, to the workers.

3) Sell the Program to Management: Unquestionably, the first big hurdle to overcome in establishing a quality control program is to sell the program to management. While no "sure fire" approach can be set up in all cases, certain basic sales principles are essential. Certainly, management must recognize a need for quality control. The presentation of well founded estimates of cost reductions (more than sufficient to support the program) is a necessity.

It is further suggested that several, well chosen, trial installations can be of great value. If successful, they are more potent than words in selling the quality control idea. If they are not successful, it will probably follow that the program is not ready to be sold.

4) Establish a Quality Control Staff: Many, many thoughts have been uttered and written in recent years concerning the place of the statistical quality control group in the industrial organization chart. It is beyond the scope of this paper to outline the pros and cons of this problem. Suffice it to say, it is a problem which requires serious consideration and can best be determined in each individual case, consistent with existing organizational structure and company policies.

In the author's case, a well established Inspection Department has existed for years. This department is headed by the Superintendent and Assistant Superintendent who report to general management at the same level as the production departments. Some sixty inspectors, most of whom, incidentally, are on a piece work system of pay, are directly supervised by three inspection foremen. In recent years, a "technical inspection" group of five men was added to the department. These men were essentially roving inspectors in the machining stages of production.

With such an organization existing, it seemed illogical to establish a separate quality control group. It was the author's opinion, shared by management, that the two groups should, by and large, be jointly organized. The problem of integrating the established line inspection group with the statistical quality control group, of merg-

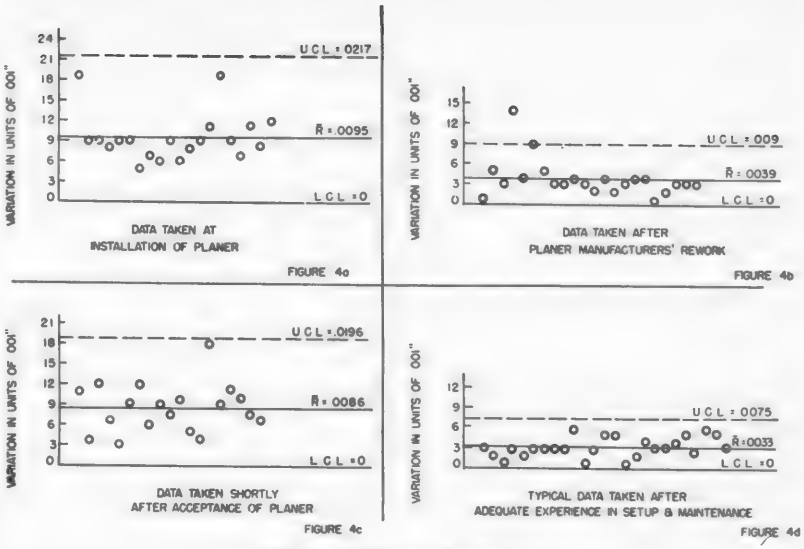
ing a one hundred percent inspection system with a statistical sampling system, replacing in some instances, one hundred percent inspection with sampling inspection, and above all merging the thinking of the "old school and the new"—these remain a major concern to the author. To date, because of the varying areas of operation, the problem has not "come to a head", but most surely it will and it must be met with a smooth, well planned means of reconciliation.

The "technical inspection group" previously mentioned formed a natural nucleus around which to develop the quality control program. The quality control staff, as such, consists of two men, a Quality Control Engineer and a Quality Control Coordinator. The author was fortunate in being able to obtain the services of a wood technologist who has completed graduate work in quality control as applied to woodworking. The Quality Control Engineer is essentially responsible for developing the technical aspect of the quality control system and the establishment of statistical sampling techniques. The Quality Control Coordinator is primarily concerned with developing the promotional aspects of quality control, publicity, training programs, quality report systems, etc. This man was chosen from the existing group of technical inspectors.

The author realizes fully that existence of such an inspection function as has been outlined and the practicality of building such a staff as outlined is beyond the scope of most wood working plants. It is suggested that a logical approach might be to select a young, alert engineer within the organization—one who has displayed outstanding ability to get along well with others—and send him to one of the ten day condensed quality control courses offered by many leading universities. The author is familiar with several highly successful quality control programs that have been started in that way.

5) Set Goals and a Time Table: It is as essential to a quality control program as it is to any promotional venture (and that, indeed, is what a quality control program is) to have some well defined goals set and to establish a time table for accomplishing them. Such a plan will, it seems, tend to prevent the quality control program from becoming merely another "bureaucratic appendage" in an organization.

6) Sell Quality Control at all Levels: If a quality control program is to achieve the maximum of success, all levels of the organization must be sold the "Quality Control Idea." If



RANGE CHARTS ON WITHIN-CORE VARIATION IN THICKNESS AS PRODUCED BY PLANER "TYPE B"

FIGURE 4

for example, intermediate supervision merely tolerates quality control, the chances for success are immeasurably reduced.

In the program under discussion, a training course, consisting of five, one and one half hour sessions, was developed to explain the technical principles, aims and methods of statistical quality control to supervision. The value of allowing time for discussion should be emphasized, for much can be learned from the questions of operating personnel! A rather extensive manual was also prepared to supplement the course. It is well to suggest that careful thought be given to the problem of explaining statistics to "old line" foremen!

This training course has been given to all members of management, all department heads and to about forty foremen, setup men and technical personnel, including engineers and time study men. As the quality control program progresses into new areas of operation, those foremen so affected are given the training course.

Full use of plant newspapers, bulletin board releases, employee letters, etc., should be part of the basic planning for quality control.

The existence of adequate lines of communication between workers and all levels of supervision is as vital to the growth of quality control program as feeder roots are to the growth of a tree. The larger the organization, the more difficult is the problem of communication because of the resultant decrease in personal contact—the most effective of all means of communication.

Dr. J. M. Juran has reported that in a survey of thirty nine companies who had installed quality control, the biggest single cause of failure lay in not securing the active participation of shop personnel.

While it is time consuming, the author has found it highly rewarding to talk, personally with each operator (in the presence of his foreman) before setting up statistical quality control on his operation, explaining in simple shop language what the average line, control limits, etc., are, what the overall plan is, and why quality work is essential to the company's well being and thus to his well being. In all cases the operator is asked for suggestions as to ways and means of quality improvement on his particular job. It is amazing what can be learned from operators, if only they are given a chance to be heard!

7) Pick "Bread and Butter Jobs": It is essential in the successful development of a quality control program that, at the earliest possible moment, it be able to pay its own way. It is, then, only "smart business" to carefully pick several applications of statistical quality control that will pay off handsomely. Nothing will more quickly establish quality contral as a vital part of the organization in the eyes of management than for it to quickly become self sufficient. The psychological effect in creating a desire for quality control among production supervision is, of course, greatly enhanced by a few highly successful applications of statistical quality control.

The author is pleased to report that in the fairly extensive program described herein, quality control, in about six months time had paid off the initial investment (which included new

office facilities among other things) and was "paying its way" currently.

8) Promote Quality Mindedness: All too often the blanket charge is leveled that the worker of today just doesn't "give a hoot" about the quality of work he does. The author's experience in talking with operators does not bear this out. One of the prime urges of all mankind is the urge to be recognized and one of the most straightforward roads to recognition is by doing one's job well. This prime urge must be cultivated at every opportunity. The worker must be made to realize fully that doing good work is ultimately in his best interest.

How to accomplish this is a difficult task. Surely, no better time exists to sell the idea of quality workmanship than when an employee is first hired, yet how few companies in their orientation programs do so! The author is happy to report that it is done in his company.

In the training course outlined previously, all foremen are urged to spend three minutes each day talking quality to one operator and to see that each operator is shown, perhaps by visitation of subsequent operations, why it is essential that he do his job correctly. Such a program, if followed extensively would unquestionably result in a much higher degree of quality mindedness.

There is, of course, much value to be obtained through use of quality posters, displays of defective work, reprints of customer complaint letters, etc. To date, the author's program has utilized some of these devices only on a limited basis and their value cannot as yet be evaluated.

It is felt, however, there can be no effective substitute for personal contact with operators in developing quality mindedness. The impact of a member of top management going out into the shop to compliment an operator on a good quality record is terrific!

9) Establish Adequate Report Systems: To be of any value, the facts gleaned from a statistical approach to a quality problem in manufacturing must be transmitted *promptly, accurately* and *concisely* to the parties in a position to take corrective action. Similarly a means of frequently and regularly reporting overall progress of the quality control program to management should be found. The problems of establishing an adequate filing system for control charts should not be overlooked.

Again no panacea exists in the way of forms, charts, etc. They must be suited to the needs of the individual company.

10) Establish Standards: In the author's opinion, one of the greatest advantages to come to the wood industry from the use of statistical quality control techniques will be that they will force us, for the first time, to define our quality standards. Such vague statements as "Make it like the print and you'll have no trouble" or "The finish on that panel is not up to our standard quality" have long plagued the furniture industry. In today's mass production scheme of things, it is essential that the worker know exactly what quality is required, whether that quality characteristic be length, width, color, or finish.

The metal trades long ago recognized one of the fundamental principles of statistical quality control (although, perhaps, not originally identifying it as such) that no two parts are *exactly* alike, that variation is always present. When this principle was recognized, tolerances on dimensions were set, thus permitting random assembly rather than selective assembly and making interchangeability of parts a reality. That these steps were highly instrumental in the rapid development of the American productive capacity is well known.

The author believes that the development of the furniture industry into a mass production enterprise will force the establishment of tolerances and definite quality standards, several hundred years' practice to the contrary, not-with-standing.

It is well to note that the author's experience has shown that the worker welcomes definite quality standards because, for the first time, he really knows what is expected of him.

Some Applications of Statistical Quality Control to Cabinet Making

The examples chosen for discussion herein were selected to illustrate that statistical quality control techniques are applicable to problems in furniture manufacturing and to emphasize, not the mystical connotation frequently given to statistical endeavors, but the fact that these statistical techniques represent a sound, logical and realistic approach to a quality problem.

Case Study "A"—Depth of Hinge Seats on Portable Sewing Machines

To present a satisfactory appearance and to prevent hinges on sewing machine cabinetwork from snagging the material being sewn, it has been a long standing inspection requirement that such hinges must be flush to 1/64 in. below the adjacent surface.

The exploded view in Figure 1-d shows the nature of this hinge seat on portable sewing machine bases and the barrel type hinge used. The author had no knowledge of any appreciable difficulty in his own plant with the fit of these hinges. When some of these bases were "trimmed" at one of our plants, a letter of complaint on the varying depths of this boring spot lighted the problem. The author was amazed to learn that for years, two thicknesses of fibre washers had been furnished at the assembly stage to shim under these hinges! This problem appeared to be suited to study by statistical quality control methods and was adopted as one of several trial installations set up to sell the entire quality control program to management.

A sampling inspection was set up at the boring operation measuring the depth of hinge seats on ten successive bases approximately every half hour. When twenty such series of observations (subgroups) had been made, the average or $\overline{\overline{X}}$ line, the average range ($\overline{R}$) and three sigma control limits on range and averages were calculated. This initial control chart is shown in Figure 1-a. Remembering that each point on the chart represents the average of the measurement of ten pieces and that the individuals must vary on either side of the average, a study of this data in relation to the specification limits clearly shows the operation is not exhibiting a state of good control. All measurements were taken in increments of 1/64 in. The specified depth of boring is shown on all charts as zero and deviations therefrom in decimal parts of 1/64 in. It will be noted in Figure 1-a that the process average is centered well above zero indicating the need for frequent shimming of hinges.

At this point, the problem, as evidenced by the complaint letter, and the quality control inspection approach to be used, was fully explained to the operator (who by this time was quite curious). This proved to be a very wise move, for very quickly it became apparent that because of the age of the equipment being used, the problem was essentially one of operator influence. The control chart was posted and maintained at the boring machine. It was pointed out to the operator that the chart would show the good work he did as well as the bad work.

Figure 1-b shows the data taken approximately ten days later. It is apparent that the performance on this specific quality characteristic—the depth of boring—had been greatly improved. The process average, or $\overline{\overline{X}}$ line, is more closely approaching zero and the width of the control limit band had decreased indicating an im-

proved state of control. It will also be noted that the average range ($\bar{R}$) has decreased indicating less variation within the subgroup of ten parts—the result of improved operator performance in this case. The lower control limit for range so nearly approaches zero in Figure 1-b that it is insignificant.

The use of washers for shimming purposes was virtually abolished and, in the past year, only very rarely has it been necessary to do any adjustment in the seating of these hinges. Figure 1-c shows data taken about one year after the initiation of the control chart. This chart represents the remarkable state of control that has, but for two brief periods when operators were changed, been maintained for over a year. In Figure 1-c, the average range and upper control limit on range are omitted for reasons of clarity.

The amount of sampling inspection was reduced first to an hourly check, then four times a day, then twice a day, then once a day and now is done about twice a week! Likewise the subgroup size has been reduced from ten pieces to four pieces.

Case Study "B"—Inspection of Incoming Shipments of Lumber

For years, each shipment of lumber purchased was inspected upon receipt for grade and footage. Because of the diversity of usage of lumber, neither the grade nor the footage were, individually, of prime importance. The interrelation of grade and footage as it affected the dollar value of the shipment, was the "quality characteristic" being studied. The comparison then, of the shipment value, as determined by the receiving inspection, to the invoiced value was of primary importance.

Upon the installation of complete new lumber handling and drying facilities, the possibility of a sampling inspection of carloads of lumber was suggested.

The past performance of each supplier—received value versus invoice value—was carefully scrutinized. It was found that sufficient data existed (twenty shipments within a span of a couple of years) on five suppliers, whose past performance merited the confidence, to set up a sampling inspection system.

Figure 2 shows the performance record of Supplier "A". For purposes of clarity, the data is shown as a percentage relationship between the value differential of the receiving inspection value and the invoice value as compared to the invoice value. Thus, it can be seen from the $\bar{\bar{X}}$ line that Supplier "A" has a record of furnishing on the average, about five percent more dollar value than was charged.

Since the data for these charts consisted of individual, independent values, the "floating average" method of statistical treatment was adopted to establish control limits. Discussion of this statistical technique is beyond the scope of this paper. Suffice it to say, that each point on the chart represents the average of two values, taken in mathematical series 1–2, 2–3, 3–4, 4–5, etc.

The chart shows a rather wide dispersion of data, probably indicating that the supplier's inspection is somewhat erratic. However, in view of the obvious attempt to give more dollar value than charged, a plan was adopted with Supplier "A" of inspecting every third shipment. The last four points on the chart represent five shipments inspected since the inception of the plan. It is apparent that the process is operating within the control limits and thus points can be expected to range from 3.4% to 13.2%, 99% of the time. Consideration is being given to reducing the sampling to every fourth carload shipment.

This application of statistical quality control has been in operation for about one and one half years. In the first year, the cost of the inspection of thirty-five carload of lumber was saved. Data is being kept on all other suppliers not now under the plan with a view towards adopting further sampling plans. The great value of such a program as this as a guide to a sound purchasing policy is, of course, obvious.

Case Study "C"—Efficiency of Hand Loading of Leg Squares Into Trucks

Lumber squares for sewing machine cabinets and stool legs are purchased from outside suppliers or from our southern plants. At one time, these squares were unloaded by hand from the freight car and loaded into factory trucks for delivery to the dry kilns or, in the case of kiln dried squares, to the cut-off and turning operations.

The Production and Material Control Department, under whose supervision this work was done, wished to place the unloading work on a piecework basis and was concerned with the care that would be shown in loading the squares after the work was done on a piece rate. Careless loading would decrease the number of squares per truck, thus requiring more trucks and floor space.

It was, then, at the request of the Production and Material Control Department, that performance of this loading job was studied by statistical quality control methods. Figure 3 shows the average and range chart constructed from data consisting of thirteen subgroups of three truck loads each. The unit of measurement was the number of pieces per truck.

Due to the relatively large dispersion shown in both the average chart and the range chart, which was due largely to the variation in size of trucks used and not to the lack of care in loading (data taken on work done on hourly rate), it was felt to be advantageous to use two sigma control limits. Thus the chart was made more sensitive to additional variation in the number of pieces per truck, which condition could occur, by and large, only through careless loading. Out of control points could then be considered cause for suspicion of careless loading.

The average chart shows that an average of 582 legs per truck was found and that 95% of the time (two sigma limits) the quantity per truck will vary from 565 to 599 leg squares.

While the data was never actually used as a check on the loading efficiency under a piece work system of pay, since shortly after the study the entire loading procedure was changed, the approach to the problem may well represent an answer to maintaining quality after work is placed on an incentive pay system. The author would question the advisability of undertaking studies of this type, however, except at the specific request of the operating department, because of the likelihood of resentment on the part of the operating department.

Case Study "D"—Within Panel Variation of Thickness on Lumber Cores for Veneered Panels

The installation of new lumber handling, and drying facilities and a new rough dimension line was accomplished in the author's plant during the early stages of the quality control program. These installations prefaced the installation of hot pressing techniques in the veneer laying operations. The installation of statistical quality control techniques on these operations, from kiln drying and swing-sawing on through core building in a Plycor machine and planing of cores, was a major undertaking.

Of considerable concern, in the search for ways and means of reducing loose veneer on panels, was the control of variation in thickness within a core. The advice of The Forest Products Laboratory that a within-core thickness variation of .005 in. was a reasonable requirement led to the adoption of this figure as a standard.

For many years, only planers made by Manufacturer "A" had been used

in the author's plant. Suffice it to say, when the finishing planer, made by Manufacturer "B" was installed in the rough dimension line, upon the recommendation of the Engineering Department, considerable misgivings concerning the new planer existed on the part of the personnel charged with operating it and maintaining it. The author presumes similar situations to occur in most plants!

It was with this background, that quality control, asking for control of thickness variation within a core of .005 in. as received out of the planer, entered the picture. An $\bar{\bar{X}}$ and R chart was set up, using a core as a subgroup and taking four micrometer measurements, one near each corner of the core. Care was taken to always record the data in the same manner, the first measurement being the corner first entering the planer and the subsequent measurements being taken clockwise around the core. This orderly recording of data later provided invaluable information. Because the range chart portion of the $\bar{\bar{X}}$ and R chart, in this instance, clearly indicated the ability of the planer to produce a uniform thickness within a core, Figures 4a, 4b, 4c, and 4d show only the range ($\bar{R}$) charts. The part played by the average ($\bar{\bar{X}}$) chart, in showing correctness of planer set up compared to a thickness standard and the ability of the planer to hold that average thickness from core to core over a long run, is beyond the scope of this discussion.

Figure 4a shows the data first taken on planer "B", the machine in question. It will be noted that the average variation in thickness within a core was .0095 in. ($\bar{R}$) with a reasonable expectancy of obtaining cores with a thickness variation as high as .0217 in. (upper control limit). Clearly, this performance of planer B was unsatisfactory. Simultaneously, similar data, for comparison purposes, was taken on a planer of Manufacturer "A". Here, the ($\bar{R}$) was approximately .005 in. Needless to say, the misgivings of the operating personnel were not relieved by these studies!

Manufacturer "B" was called in to improve the performance of the planer. After considerable investigation and, on the basis of data accumulated by quality control techniques in the manner previously described, Manufacturer "B" concluded that the lower planer shoes were warped, or at least were not parallel. When the planer was torn down, it was found that one shoe was warped approximately .017 inches! With this difficulty corrected by the manufacturer, data shown in Figure 4b shows a decided improvement, the average range $\bar{R}$, having been reduced from .0095 in. to .0039 in. and the upper control limit reduced to .009 in.

This improvement however, was very short lived. Figure 4c shows data taken two days after the planer had been revamped. The average range had jumped back up to .0086 in. and the upper control limit to .0196 in. Again this performance was unsatisfactory. The manufacturer had discharged his responsibility and it clearly was up to the operating personnel to take the action necessary to obtain proper performance. At a conference of all interested parties, the superintendent of the operating department, sensing the situation, "broke the case wide open" by openly stating his doubt as to the ability of his expert setup man to correct the situation. This provided the spark of incentive needed! Within a couple of weeks, the planer was operating very well and has continued to do so since! Figure 4–d shows recent data taken. It is apparent that the control of within-core thickness variation has been obtained and is being maintained. The climax was reached when the setup men and foreman, who had for so long entertained misgivings about planer "B", asked the author to set similar charts on planers of Manufacturer "A" since they were not performing as well as planer "B"!

The author is pleased to report that the immediate supervision concerned with this planer follow the quality control charts closely, resetting the planer, grinding the knives or taking any other action required, when the control charts show a drift in quality and before defective work is produced.

Case Study "E"—Inspection of Incoming Veneered Panels

Since a large volume of the veneered panels used in the author's plant are obtained as rough veneered panels from our southern plants, it was immediately apparent, that if control of quality was to be maintained in the machining and sanding operations, an effective screen must be set up to insure that the quality of material entering these processes be controlled at an economical quality level. The "break even" point lies where the cost of inspection exceeds the cost of letting a few defective articles enter the process.

The author's experience, paralleled, no doubt, by most people concerned with the management of inspection, long ago led him to realize that one hundred percent inspection is no assurance of one hundred percent accuracy! Since one hundred percent inspection appeared to be too costly anyway, sampling inspection seemed to hold the answer.

The statistical quality control technique of acceptance sampling and the many published plans thereunder were studied in detail. The acceptance sampling plans adopted for this application were those published by the Columbia Statistical Research Group.

It had been a long standing practice to charge back to the supplying plants the cost of excessively defective material. However, the inadequate "spot checking" and the lack of proper organization of this inspection all too frequently permitted the cost of this defective material to be absorbed in the production process.

Through discussion of the objectives of the overall plan, an agreement was reached with the supplying plants to charge back the cost of defective material above and beyond a predetermined quality level.

However, a plan of this sort which merely transfers the cost of defective material from one plant to another within the same organization falls far short of the desired objectives. The only real gain can be made when the supplying plant can effectively improve their quality.

With the aid of a manual, prepared to fully explain the details of the sampling plan, and close coordination between plants, the supplying plants are setting up the same acceptance sampling procedures prior to shipment. Thus the magnitude and nature of defects can be readily detected at source and, it is hoped, will provide the impetus for courses of action to effectively reduce the amount of defective material produced.

In a program of this sort, frequent visits by both supplier and consumer are of inestimable value.

One of the principal problems to be overcome in this inter-plant quality control was the establishment of clear, concise standards. A comprehensive manual of inspection standards was prepared, defining, among other things, the tolerance on overall size, the short and narrow veneer tolerance, the various types of defects such as split veneer, mismatch of spliced veneer, warp, etc. and the degree to which they could be tolerated, and the grade of veneer to be used. The use of photographs has proven useful in defining many of these visual quality characteristics.

Conclusions

The author is convinced, more so than ever, after better than two years experience in the actual application of statistical quality control techniques to

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Effective Quality Control on End Product

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A discussion of procedures used to control product quality on an industry-wide basis. Formal industry standards with enforcement by means of inspection and testing have resulted in an enviable reputation for product quality of Douglas fir plywood. Rigid acceptance tests for glues and for practices affecting surface grades are enforced to assure uniform product quality.

Introduction

AN INDUSTRY-WIDE quality control program such as described here is directed towards controlling quality trends or levels. The theory behind such a program holds that sampling and testing can indicate significant changes in quality levels. Reliance is placed upon the development of complete data to account for any changes in mill quality level so that a basis for corrective measures is already formed if tests indicate a falling off in quality.

There is a significant difference between this approach to the problem and that of most individual plants. In the latter case, efforts are generally directed towards controlling the quality of each shipment, the degree of control being dependent upon the effectiveness of the plant system.

Where plant quality control programs exist, a policy of close cooperation between industry and mill programs insures close control of product quality.

Basis for a Quality Control Program

Effective quality control is predicated upon strict standards. Probably almost all manufacturing plants make use of some sort of quality control over the end product and a great many make use of the most advanced sampling, testing, and statistical techniques to assure product quality. However, unless fixed standards are adhered to by mills manufacturing a common product, a great deal of harm may be done by those operators who may be more interested in maximum production at the expense of quality rather than a reasonable balance between these two factors. To assure uniform quality on an industry basis it is therefore necessary not only to have a written standard but to use effective measures for enforcement of that standard.

Experience in the Douglas fir plywood industry has shown that effective quality control work can be carried out on an industry-wide basis. A policy of universal agreement by the producing mills to specified quality standards and the willingness of these mills to support a program of inspection and testing by an organization independent of individual mill control have resulted in effective and realistic industry-wide quality control of Douglas fir plywood.

The Douglas Fir Plywood Association, trade promotion organization for the industry, is the agency administering the quality control program. Strictly speaking, it is not industry wide, as it includes only those mills belonging to the Association. However, since the membership is comprised of 68 mills producing some 93% of the industry's footage, I believe it reasonably accurate to refer to the program as industry wide.

Since most industries support trade associations for purposes of promotion and, to some extent, reearch, it would appear that organizations through which effective industry-wide quality control measures could be administered are in existence. Once agreement is reached concerning product standards and if inspection and testing programs to enforce standards can be made binding, through individual plant agreement, a firm industry-wide quality control program will work in any industry. Such a policy will stimulate sales as soon as customers discover the uniformity and reliability resulting from effective quality control measures.

Necessary Tools

Effective product control requires the use of inspection and testing entirely free from the influence of the production units.

Inspection and testing may be termed the tools for making a quality control program work. Use of these tools by a trade association has definite advantages as compared with individual plant application. In the latter situation inspection and testing are only as effective as mill management wants them to be. If it is expedient to ignore inspection reports and test results, who can object except, possibly, the customer? However, with administration in the hands of an agency responsible for maintaining industry standards, reports concerning quality cannot be overlooked for two reasons. First, the producers have a moral obligation to support a quality control program to which all have agreed in detail. Second, the quality control program administered by a trade association should contain very real penalties for non-conformance. The program as administered by the Douglas Fir Plywood Association authorizes use of penalty measures and though seldom invoked, they are effective.

Procedure

To best set forth the workings of an industry-wide quality control program, I believe an account of the procedures followed in the Douglas fir plywood industry and administered through the Douglas Fir Plywood Association is in order.

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When the present inspection and testing program was first undertaken in 1938 by the Association in behalf of the 18 member mills, it was agreed that the Association would hold title to and own the registered grade marks used in grade marking panels produced by the member mills. It was also agreed that if member mills did not produce plywood in accordance with the established standards, the Association had the right to repossess these grade marks. Since these grade marks were widely advertised as assurances of good plywood quality with the result that more and more orders specified grade marked plywood, it can be seen that loss of the grade marks would be a serious blow to a member mill. Thus the basis for an effective industry-wide quality control program was set.

To aid in establishing minimum standards a permanent technical committee made up of representatives from the member mills was organized to review recommendations from the industry and from the Association's technical staff. The individual mills then agreed upon a set of minimum standards as a basis of operation. It should be noted that the technical committee is still a working group and cooperates with the Association's technical staff whenever changes in standards are in prospect.

Actual product quality control is carried out by the Field Supervisory Service and the Glue Line Testing Section, both branches of the Technical Department.

Today, with Association membership expanded to 68 plants, the basic product quality control work is carried out by the 15 men making up the Field Supervisory Service. These men are commonly known as inspectors. Their primary function is twofold: 1. Panel grading, and 2. Taking samples for glue line testing. This may appear to be a rather simple job, but I believe the following, detailed account of their activities will indicate to great extent why the industry-wide quality control program has been successful.

Since mills belonging to the Association are scattered along the West Coast from the Canadian border south to Santa Rosa, a few miles north of San Francisco, it is not possible for the inspectors to work out from a central location. Therefore each man is based in a territory where he can best cover the four or five mills assigned him. These men are responsible for the quality control work in their territories. They grade panels and take test samples in accordance with procedures established by the Association. However, since they are specialists in plywood, they are frequently called upon by mill management to help iron out mill problems. On frequent occasions mill management has requested the exclusive services of an inspector over a period of time on mill problems. Members of the Quality Supervisory force are not looked upon as policemen by the mills, but rather as experts to whom they can turn for help.

Panel Grading

Panels are graded in accordance with a definite procedure. The following quote from the rules governing grading is an illustration of the industry's approach to the quality control program.

"Supervisors will grade 80 to 100 panels (100 if possible) each week in each mill. Panels shall be selected preferably in lots of 10, each lot from a different stack or location if possible, in order to get as randomized a selection as practicable.

"Whenever the Supervisor is unable to grade the quota for a week in a mill, he will double the quota the following week, using the same randomized sampling method.

"A continuous record of each mill's grade will be maintained at DFPA Laboratory (Chief Supervisor's office) in Tacoma, so that mill averages for the last 1,000 panels graded will be available at all times.

"Whenever a mill average for last 1,000 panels exceeds the industry standard for a permissible 'below grade panels', the mill will be notified promptly in writing and a two-weeks' concentrated grading will be carried on by Supervisors. During this period a minimum total of 500 and not more than 600 panels shall be graded, involving at least 4 different grading visits by the Supervisor. Panels shall be graded in lots of not more than 20, and preferably only 10, from any one load or stack, with not more than 150 panels during any one visit.

"If the average grade of these 500 (to 600) panels fails to meet industry standard, the grade marking privilege shall be withdrawn from the mill, upon notice to mill in writing by Chief Supervisor or his superior, and all DFPA stamps and brands removed."

Sampling for Glue Testing

Inspector's time is about equally divided between grading for face quality and the associated trouble shooting, and tagging samples at the glue spreader for laboratory testing.

Quotas have been set up to cover sampling of the two types of Douglas fir plywood. A minimum of 50 samples of Exterior type and 40 of Interior type is tagged each month in each mill. These are minimum figures; actually sampling usually exceeds these quotas.

Four panels are tagged at random from each press load sampled. Complete notes are made concerning stock conditions, glue spreads, temperatures, pressures, maximum and minimum assembly times, identity of glue used; in fact, all factors that could have any influence upon the glue line quality of the panels are recorded. This information is entered upon a form known as a glue data sheet, a copy of which is turned over to mill management and a copy sent to the testing laboratory. With complete information for test panels, laboratory technicians are, more often than not, able to tie test results to gluing conditions.

As in panel grading, inspectors are expected to spot undesirable gluing conditions and call the attention of the superintendent or foreman to the situation.

In addition to grading and sampling for glue line testing the inspector checks glue mixes, checks platen temperatures, takes samples of veneer for moisture content testing, and performs other tasks, all centering about the business of controlling panel quality.

Laboratory Testing

To handle the large volume of testing that goes with an industry-wide quality control program two testing laboratories are in use. The main laboratory is in Tacoma, Washington, where routine testing is carried out for mills north of the Columbia River. In addition all non-routine or special tests are carried out here, such as approval tests on new glues, tests on the effectiveness of toxic agents to inhibit mold attack on protein glue lines, and all manner of test work on problems presented by member mills. Here also is located the Research and Engineering division of the Technical Department. A second Laboratory is located at Eugene, Oregon, to serve mills in Oregon and California.

We have seen how panels are tagged in the mills for testing and that complete data are taken at this time. Samples from tagged panels are cut to approximately 1′ x 2′ and sent in for testing. In the laboratory these panels are cut into test specimens according to type. Five plywood shear specimens are prepared from Exterior panels and three standard six inch square specimens are cut from each Interior panel.

Specimens are then subjected to test according to type. Exterior specimens are put through a cyclic boiling and

drying test and broken in a plywood shear testing machine. Breaking loads are noted and wood failure is estimated after specimens have dried. Interior specimens are subjected to a ten cycle test of four hours soaking in water and room temperature and twenty hours drying at room temperature.

When tests are completed and specimens thoroughly examined, test reports are mailed out to the mill concerned.

At the end of each month a recapitulation of industry performance is mailed to the mills and to the glue companies supplying the industry. This report rates the mills in numerical order with the mills showing the best glue line record at the top and so on down. The report also lists the record for each glue used.

If any mill shows glue quality below the established standard, the Association is obligated to take action under the quality control policies. Such action consists of an immediate intensive sampling at the low mill which is confined to plywood bonded with the adhesive used in the manufacture of the original low panels. If tests on samples taken during the intensive sampling should fall below the established minimum standards, then the right to grade mark panels made with glue in question is withdrawn.

This policy has been very effective. It has resulted in the elimination of several border line glues from the industry and has stimulated realistic gluing recommendations based on reasonable margins of safety by glue suppliers. In addition to routine glue line testing an important feature of industry-wide quality control is the glue approval program. No glue can be used to manufacture panels bearing the Douglas Fir Plywood Association's grade marks unless it has passed the established glue approval tests. No control is exercised over glue formulation, or other characteristics except for the one stipulation that no protein or starch can be used in Exterior type glue lines. This prohibition stems from some sad experiences with protein extended Exterior glues under actual outdoor exposure. Approval tests on proposed glues are conducted upon plywood made with such glues under mill conditions. Test run procedure calls for manufacture of several press loads of plywood in each of three separate plants with runs scheduled so that all standard constructions of plywood are covered. At each of these runs an inspector is present to see that the glue is mixed and used according to the schedules furnished by the glue manufacturer. Glue spread, assembly times, press times, and temperatures are recorded for each press load, and approval is granted, if panels pass the tests, to the glue as actually run. This means that in addition to approving the glue as such, spreading and pressing schedules are also approved and approval is limited to the minimum conditions under which the test runs were made. Linking of glue approvals strictly to the actual gluing conditions followed during test runs is an extremely important feature of the glue approval policy. Minimum gluing recommendations as far as spread, press time, and press temperatures are thus established and cannot be altered without additional test runs to prove the validity of changes. Of course no objection is made to safe changes such as higher spreads, higher temperatures, and longer press time.

Thus far we have covered the basis for an industry-wide quality control program. We have described the policies followed and how they are enforced. I believe it pertinent to devote space here to some of the other testing activities that have become part of the quality control program. Although not of an official nature, they are a definite contribution to the over-all program.

The mere fact that laboratory facilities are available has encouraged individual mills to bring problems in. In some instances testing for individual mill problems has resulted in large scale routine testing on an industry-wide basis. For instance, years ago some moisture content testing was started as a service for one or two mills. This was done on an informal basis; sampling was sporadic but the mills considered the service valuable. Over the years moisture content testing has spread to the point where it is now a routine service for all mills. Sampling is on a regular basis and testing is an important part of laboratory work. A considerable file of worthwhile data has been developed on veneer and plywood moisture content as general information in addition to the mill service rendered.

It has also become a practice for member mills to refer new products to the laboratory for evaluation. Often the laboratory is contacted by salesmen who upon attempting to introduce a new edge sealer or patch glue, as examples, to member mills, are referred to the Association to have the product tested. Acceptance is then dependent upon the results of laboratory testing.

It may be seen from the foregoing that in addition to the formal quality control program governing grading and glue line testing, actual industry quality control includes a great many other activities which result in wider product quality control.

Perhaps emphasis should be placed upon one other factor contributing materially to effective industry-wide quality control. Data developed through panel grading and laboratory testing are the basis of monthly, quarterly, and annual reports to the industry. These reports are published for the purposes of giving individual mills a long range look at their panel quality and for comparing mill ratings with industry averages. In addition, in the case of adhesives, comparisons are made between the performances of the individual glues on the basis of test results. Such a system has the psychological effect of stimulating efforts toward ever better product quality on the part of individual mills. It is even more effective in the case of glue suppliers, as most plywood manufacturers use the monthly recapitulation of test results as a criterion of glue quality and tend to use those glues with the better records. As a result glue suppliers are constantly alert to falling off in glue line performance.

Of course such a system can be applied only through an industry-wide program.

Conclusion

We have described how an industry-wide quality control program works in the Douglas fir plywood industry. We believe a similar program can be adapted to many other industries with great profit.

Perhaps the greatest obstacle to overcome in such a program is the usual reluctance of individual mill management to accept the idea of independent inspection and testing with authority to enforce findings. Once this factor is overcome, effective industry quality control measures can be instituted.

Discussion

Edward P. McMahon (Nickey Bros., Inc.): What has been your experience in regard to the magnitude of the differences in wood failure readings between expert readers on the same specimens?

Mr. Ripley: This is a good question. We recognize that this is an important problem. We use standard samples to obtain uniformity among readers and require periodic checks against these standards. Occasionally we do find big differences from reader to reader.

Joseph P. Foley (Weyerhaeuser Timber Company): How is the sale of unapproved glues to mills controlled?

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Some Applications of Statistical Quality Control to the Drying of Lumber

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Simple applications of statistical quality control techniques to the control of the final moisture content of kiln dried lumber are described and illustrated. The Shewhart control chart is one of the essential tools in statistical quality control. By separating the quality variations which are due to assignable causes from those due to the operation of a stable system of chance causes, it indicates when corrective action may be taken to bring about improvement in product quality. The Shewhart control chart for variables also indicates the process average but it does not reveal the natural tolerances of the process. Other statistical aids to the control of the drying process also are brought out.

Introduction

IT IS GENERALLY CONCEDED that effective quality control is necessary if new markets are to be developed and old markets retained in the face of strong competition. This is particularly true in the lumber industry, beset, as it is, with a constantly increasing number of competitive products. Most of these products enjoy the comparative advantage of a high degree of uniformity. An advantage which, naturally enough, is vigorously exploited in their promotion and sale. The lumber industry can, and must, meet this challenge by improving the quality of its products.

It is the purpose of this paper to show how statistical techniques may be employed as effective tools in the control of one of the important qualities of kiln dried lumber, the final moisture content. Because of the preconceived ideas, which exist with respect to the science of statistics, the mention of statistical quality control may give rise to misconceptions concerning the techniques used and the work involved in putting them into effect. While some of the underlying theories are complex, the practical applications of statistical quality control techniques are very simple as will be seen from the examples cited later in this paper. There is also a tendency to mistrust results which are obtained by statistical methods, a tendency which is anomalous in view of the outstanding success with which, to cite but one widely known example, the National Safety Council has been able to predict the accident toll on major holidays.

Statistical treatments are applied to data in an effort to determine their true significance. A limited amount of data contains a limited amount of information and it is the purpose of statistical techniques to reveal this information while, at the same time, avoiding confusing manipulations which lead to false or unwarranted conclusions. Statistical methods should not, however, be expected to remedy irregularities or deficiencies in the basic data. Data must be protected from these faults by planning which excludes known sources of error wherever practicable. Unknown sources of error, and known sources of error which it is impracticable to exclude, may be minimized by randomization. A discussion of randomization is beyond the scope of this paper and those interested are referred to Fisher.[1]

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[1] Fisher, R. A. "The Design of Experiments", Hafner Publishing Company, New York, 1951.

The Statistical Viewpoint

To understand how statistical quality control techniques may be applied to the control of the final moisture content of kiln dried lumber, it is first necessary to adopt what is, for many, an entirely new point of view. This point of view, as stated by Grant[2] is: "Measured quality of manufactured product is always subject to a certain amount of variation as a result of chance. Some stable 'system of chance causes' is inherent in any particular scheme of production and inspection. Variation within this stable pattern is inevitable. The reasons for variations outside this stable pattern may be discovered and corrected". The foregoing statement is general. A specific statement of this point of view with reference to the kiln drying of lumber might be: The final moisture content of kiln dried lumber is always subject to a certain amount of variation due to the operation of a system of chance causes. This system of chance causes remains stable so long as no change is made in the factors by which it is determined. These include: (A) The species, thickness, weight segregation, etc. of the lumber, (B) The extent of pre-air seasoning, if any, (C) The methods and equipment used in the drying process, and (D) The drying schedules used. Variations in excess of those to be expected, from the operation of this system of chance causes, may be attributed to an accidental or intentional change that was made in one (or more) of the above mentioned factors. Such a change is termed an assignable cause of variation.

Shewhart Control Chart

It is all very well to know that some variations are due to the operation of "chance causes" and that others are due to "assignable causes" but, if this knowledge is going to serve a useful

[2] Grant, E. L. "Statistical Quality Control", McGraw-Hill Book Company, Inc., New York, 1952.

purpose, we must be able to distinguish between the two easily and with a high degree of certainty. The Shewhart control chart for variables is the essential tool in statistical quality control which makes this distinction possible. In separating the quality variations which are due to assignable causes from those due to chance causes, the Shewhart control chart performs a valuable service. It indicates when corrective action may be taken to bring about an improvement in product quality and, by identifying certain quality variations as the inevitable result of chance causes, it prevents numerous unwarranted process adjustments which, all too frequently, do more harm than good.

Attributes and Variables

Before proceeding with the development of a plan of statistical quality control, it is well to consider the nature of qualities. Qualities may be separated into two types: attributes and variables. Attributes are those qualities which are either absent or present and which, if present, fall into a limited number of discrete categories. Variables are those qualities which are always present to a greater or less degree. The measurment of variables involves the use of a scale that, in theory, may be infinitely divided.

In the case of lumber, sapwood, knots, machine burn, etc. are most frequently considered as attributes while moisture content, length, width, thickness, density, etc. are generally considered as variables. The "go, no-go" technique provides a means for measurement by attribute which is based upon arbitrarily predetermined magnitudes of a variable.

Where a quality may be treated as either an attribute or a variable, the choice of treatment will depend upon the economics of the case. When a variable is treated as an attribute, no information is developed as to how good the acceptable items are nor as to how poor the rejects are. It is, therefore, necessary to make several times more measurements by attribute than by variable to determine the level of quality with a given degree of precision.

After weighing the advantages and disadvantages of control by attribute, as compared with control by variable, it has been decided that it is more economical to control the final moisture content of kiln dried redwood lumber by treating this quality as a variable and, consequently, this paper is limited to the consideration of variables.

Construction of the Shewhart Control Chart for Variables

The first step in the construction of the Shewhart control chart for variables is the collection and recording of the basic data which, in the examples to follow, is the final moisture content of kiln dried redwood lumber expressed as a percentage of the oven-dry weight. It is unnecessary, if not actually undesirable, to attempt to determine the moisture content of every piece of lumber that is dried. It will suffice to determine the moisture content of a representative sample. Since the moisture content of the entire kiln output will be judged on the basis of the information obtained from the sample, it is vital that a procedure be set up which will ensure that the sample is truly representative. Several such procedures suggest themselves. In an operation where all the kiln dried lumber is put over a dry sorter as soon as it is taken from the cooling sheds, a convenient procedure would be to take, as samples, the 10th, 20th, 30th, etc. boards to pass a designated point after a given time. The sample boards should be identified, with appropriate numbers, as soon as they are selected so that their moisture contents will be recorded in the same order as they were obtained. Alternatively, sample boards may be obtained from each kiln charge. When samples are obtained in this way, they should be selected in accordance with some pattern, the elements of which have been predetermined by chance. By way of contrast, sample boards, chosen as a result of individual whim, would be of very doubtful value.

Sample boards taken from the dry sorter or directly from the kiln charges will form a satisfactory basis for a control chart. If taken directly from the kiln charges, the records should show the location, in the charge, from which each sample was obtained. In either case, it is desirable to retain the identity of the kiln charges from which the samples were obtained.

Oven sections should be cut from the sample boards and weighed as soon as possible after the samples have been chosen so as to minimize errors. The moisture content of each sample expressed as a percentage of its oven-dry weight, is calculated to the nearest tenth of a percent and this information is recorded. In order that they may yield all the information possible, the data are arranged in subgroups. These subgroups may be comprised of from two to twenty consecutive samples. Five is, in many respects, an ideal subgroup size. If it is desired to make the control chart more sensitive to minor changes in the process average (average moisture content), a subgroup of ten is recommended. The total number of samples taken will depend upon the subgroup size chosen. When the control chart shows that the process is in control, enough samples to make two subgroups per kiln charge probably will be sufficient. When starting a statistical quality control program or when trying to bring a process into a satisfactory state of control, it may be advisable to obtain sufficient data for four or more subgroups per kiln charge.

By way of illustration, let us consider the case of a mill where a program to apply statistical quality control techniques, to the control of the final moisture content of kiln dried redwood lumber, is being inaugurated. The following assumptions are made:

1. That, at the outset, the program will be limited to 4/4 uppers which were originally "heavy segregation" since lumber of this type constitutes the bulk of the kiln output of the mill in question.
2. That the lumber is pre-air dried to an average moisture content of 40 percent before being kiln dried.
3. That specifications require that 90 percent of the kiln dried lumber be below 10 percent moisture content and that none of the lumber be above 15 percent moisture content.

It was decided to group the data into subgroups of five and to take enough samples from each kiln charge to form two subgroups. The subgroup number, kiln and charge number and the moisture content of each sample were recorded. The average ($\bar{X}$) of each subgroup was computed by totaling the percentage moisture contents of the samples in the subgroup and dividing by the number of samples. The range (R) of each subgroup was computed by subtracting the smallest value in the subgroup from the largest.

The data resulting from the first 100 samples (20 subgroups) is set forth in Table 1. Since the significance of the data, in Table 1, is not readily discernible, it must be manipulated further. The first step is to plot the average ($\bar{X}$) and the range (R) of each subgroup. The two values ($\bar{X}$ and R) for each subgroup should be plotted on the same chart as was done in Figure 1. The next step is to calculate the grand average ($\bar{\bar{X}}$) and the average range ($\bar{R}$). Continuing with our example:

$$\bar{\bar{X}} = \frac{\text{Sum of subgroup averages}}{\text{Number of subgroups}} = \frac{178}{20} = 8.90 \text{ percent}$$

$$\bar{R} = \frac{\text{Sum of subgroup ranges}}{\text{Number of subgroups}} = \frac{41.8}{20} = 2.09 \text{ percent}$$

$\bar{\bar{X}}$ and $\bar{R}$ are represented on the chart by continuous horizontal lines. The next step is to calculate the upper and lower control limits for $\bar{\bar{X}}$ and R. They are calculated according to the following formulas:

Upper control limit for $\bar{\bar{X}} = UCL_{\bar{\bar{X}}} = \bar{\bar{X}} + A_2\bar{R}$

Lower control limit for $\bar{\bar{X}} = LCL_{\bar{\bar{X}}} = \bar{\bar{X}} - A_2\bar{R}$

Upper control limit for $R = UCL_R = D_4\bar{R}$

Lower control limit for $R = LCL_R = D_3\bar{R}$

The factors needed to solve these formulas are given in Table 2 below.

Table 2—FACTORS FOR DETERMINING THE 3-SIGMA CONTROL LIMITS FOR $\bar{X}$ AND R CHARTS

Number of samples in subgroup	A_2	D_3	D_4
5	0.58	0	2.11
10	0.31	0.22	1.78

Substituting in the formulas:

$UCL_{\bar{\bar{X}}} = 8.90 + (0.58)(2.09) = 10.11$

$LCL_{\bar{\bar{X}}} = 8.90 - (0.58)(2.09) = 7.69$

$UCL_R = (2.11)(2.09) = 4.41$

$LCL_R = (0)(2.09) = 0$

The control limits are represented on the chart by broken lines. They may be projected into the future but new control limits should be calculated as soon, after an operational change has been made, as sufficient data (about 20 subgroups) is accumulated. New control limits should also be calculated if the control chart indicates that there has been a sustained shift in either range or average.

Figure 1 is the Shewhart control chart for variables towards which we have been working. It tells us that, under current operating conditions, the output of these dry kilns is such that the average moisture content of subgroups of five samples ($\bar{X}$) may be expected to vary between 7.69 percent and 10.11 percent and that the range of moisture contents within each subgroup (R) may be expected to vary between zero and 4.41 percent. It tells us that variations in excess of these limits are, in all probability, due to assignable causes which can be found and corrected. It also tells us that variations within these limits are due to a system of chance causes which is inherent in this particular drying operation and, if we wish to reduce these variations, it will be necessary to make a basic change in the drying operation.

Upon examination of the control chart, it immediately becomes apparent that two points (subgroups 7 and 16) are outside the control limits on the chart for averages and that one point (subgroup 15) is outside the control limits on the chart for ranges.

Since the control chart indicates that subgroups 7, 15 and 16 reflect the operation of assignable causes, an effort should be made to determine the nature of these causes. An examination of Table 1 shows that the samples which comprised these subgroups were dried in kiln number 2. Further investigation is necessary to determine the cause of the trouble. With the control chart indicating that there is an assignable cause to be found and with the finger of suspicion pointing at kiln number 2, the source of the trouble will probably be discovered. Among the possibilities that should be investigated are:

1. The kiln schedules, which were used to dry these two charges (2–2 and 2–4), may have been modified.
2. One or more of the heating coils in this kiln may be functioning erratically; perhaps because of faulty traps.
3. The doors may not close tightly thus allowing excessive air leakage.

Other possibilities will suggest themselves to those familiar with the kilns and their method of operation.

Table 1—PERCENTAGE MOISTURE CONTENT OF KILN DRIED 4/4 REDWOOD UPPERS

Subgroup number	Kiln and charge number	Sample a	b	c	d	e	Average $\bar{X}$	Range R
1	1-1	8.0	7.5	9.2	8.2	7.0	8.0	2.2
2	1-1	8.5	8.4	9.5	8.9	7.8	8.6	1.7
3	2-1	7.6	7.6	8.7	8.3	8.4	8.1	1.1
4	2-1	7.3	8.2	8.8	8.9	8.1	8.3	1.6
5	1-2	8.1	7.7	8.1	8.4	8.1	8.1	0.7
6	1-2	7.8	8.6	9.4	9.1	8.9	8.8	1.6
7	2-2	8.4	10.0	9.5	12.1	12.0	10.4	3.7
8	2-2	9.3	9.7	10.2	10.8	10.0	10.0	1.5
9	1-3	8.9	8.8	10.4	8.9	8.0	9.0	2.4
10	1-3	8.5	10.6	9.0	8.8	9.9	9.4	2.1
11	2-3	7.7	9.2	10.3	9.0	10.8	9.4	3.1
12	2-3	8.5	9.7	7.2	8.6	8.3	8.5	2.5
13	1-4	8.9	9.0	8.0	8.0	9.4	8.5	1.4
14	1-4	8.2	8.3	7.7	8.7	8.1	8.2	1.0
15	2-4	8.4	10.8	9.9	13.1	8.5	10.0	4.7
16	2-4	11.1	12.2	8.8	10.1	9.8	10.4	3.4
17	1-5	9.0	10.1	8.5	9.1	8.6	9.1	1.6
18	1-5	7.6	8.8	8.5	8.3	8.4	8.3	1.2
19	2-5	7.0	9.8	8.1	9.4	8.6	8.6	2.8
20	2-5	7.8	7.7	9.2	8.7	8.2	8.3	1.5
Totals							178.0	41.8

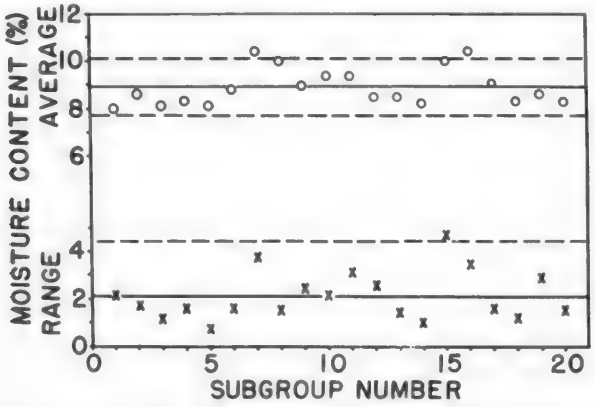

Figure 1.—Moisture content of kiln dried 4/4 redwood uppers: Shewhart control chart for averages and ranges (subgroups of five).

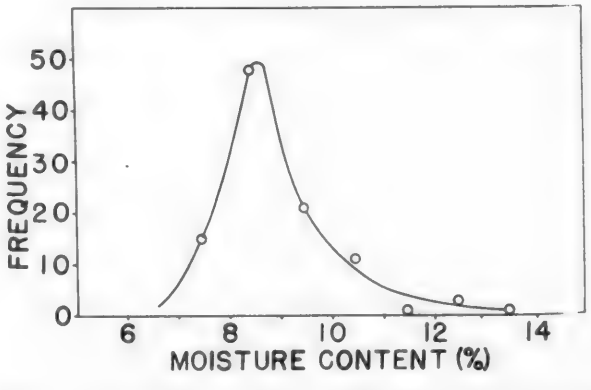

Figure 2.—Moisture content of kiln dried 4/4 redwood uppers: frequency distribution of individual sample measurements.

Other Statistical Aids to the Control of the Drying Process

While the Shewhart control chart is probably the most potent tool used in statistical quality control, other statistical tools can serve valuable purposes. Frequency distribution and cumulative frequency curves are easy to understand and provide needed information. If the individual moisture contents tabulated in Table 1 are tallied according to their magnitude with all samples having a moisture content of from 7.0 percent to 7.9 percent tallied together in one group and those having a moisture content of from 8.0 percent to 8.9 percent tallied together in a second group, etc. a compilation, such as Table 3, would result.

Table 3—GROUPED FREQUENCY DISTRIBUTION OF MOISTURE CONTENT OF KILN DRIED 4/4 REDWOOD UPPERS

(Data from Table 1)

Midpoint of Group	Upper Boundary of Group	Frequency	Cumulative Frequency
7.45%	7.95%	15	15
8.45	8.95	48	63
9.45	9.95	21	84
10.45	10.95	11	95
11.45	11.95	1	96
12.45	12.95	3	99
13.45	13.95	1	100

The data from Table 3 is shown graphically in Figures 2 and 3. To construct Figure 2, the frequency of each group of moisture contents was plotted at its midpoint. A smooth curve was drawn through the plotted points as such a curve more nearly represents the population, from which these samples were drawn, than would an irregular line connecting the points. This curve is slightly lop-sided due to the nature of the lumber drying process. In the particular drying operation from which these data were obtained, the equilibrium moisture content was never lower than 4.3 percent and, as a consequence, the left hand limb of the frequency distribution curve cannot extend beyond that figure. No factor of this nature operated to restrict the right hand limb of the curve.

Lop-sided curves are said to be skewed. This curve is positively skewed. A small amount of skewness, such as this, may usually be disregarded without serious consequences. In this process, the skewness will probably decrease when the conditions, which caused subgroups 7, 15 and 16 to be out of control, are corrected.

Figure 3 was constructed by plotting the cumulative frequencies, shown in Table 3, at points which corresponded to the upper boundaries of the groups and then drawing a smooth curve through the plotted points. The frequencies were plotted at the upper boundaries of the groups since the cumulative frequency shown for each group was the total number of occurrences below the upper limit of the group.

Frequency distribution curves are easier to interpret when the frequencies are expressed as percentages rather than as number of occurrences. The frequencies given in Table 3, are numerically equal to the corresponding percentages since exactly 100 measurements were tabulated.

The skewness, mentioned in connection with Figure 2, is also evident in Figure 3. It accounts for the lack of symmetry in the curve.

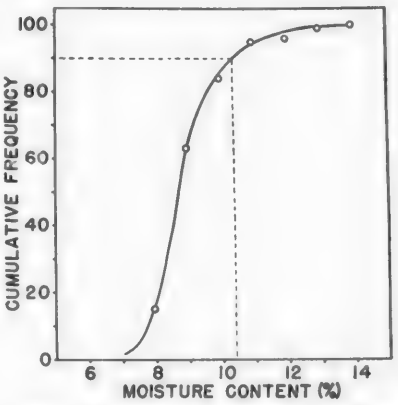

Figure 3.—Moisture content of kiln dried 4/4 redwood uppers: cumulative frequency of individual sample measurements.

Figure 3 may be used to determine whether or not the drying specifications are being met. A brief inspection of the curve indicates that little, if any, of the lumber exceeded the upper specification limit of 15 percent moisture content. The other specification was that 90 percent of the lumber be below ten percent moisture content. To check this specification, enter Figure 3 from the right hand margin at the point which corresponds to a cumulative frequency of 90 percent. Move horizontally to the curve and then move vertically to the scale at the bottom of the figure where the moisture content may be read. In this example 90 percent of the lumber is not below ten percent moisture content but 90 percent is below 10.4 percent moisture content. This indicates that, to meet specifications, the curve must be shifted to the left by an amount equal to 0.4 percent on the moisture content scale. Since a minor shift in the curve will not have an appreciable effect on its shape, we may assume that if the kiln drying time is increased and/or the drying schedules are modified so that the average moisture content of the dry lumber is reduced by 0.4 percent (from 8.90 percent to 8.50 percent) the specifications will be met. As was indicated in the discussion of Figure 2, correction of the conditions which caused subgroups 7, 15 and 16 to be out of control will change the distribution of moisture contents. This will probably enable the operation to meet specifications by making a lesser reduction in the average moisture content. After the indicated adjustment has been made, a new cumulative frequency curve, based on new data, should be prepared to determine what, if any, additional adjustment is required. Manson[3] has shown that the frequency distribution curves, obtained by plotting frequency against the logarithm of the moisture content of kiln dried lumber, are virtually normal. He has further shown that more precise adjustments of the drying process may be made when calculations are based on logarithms of the moisture contents rather than on the moisture contents themselves. While this more precise approach to the statistical quality control of the final moisture content of kiln dried lumber permits more accurate adjustments of the drying process than does the "cut and try" approach described in the example above, it is felt that its greater complexity will limit its use to those who are well versed in statistical methods.

Summary

Statistical quality control techniques may be employed as effective tools in the control of the final moisture content of kiln dried lumber. The Shewhart control chart is probably the most potent of these tools. By separating the quality variations which are due to assignable causes from those due to the operation of a stable system of chance causes, it indicates when corrective action may be taken to bring about improvement in product quality. The Shewhart control chart for variables also indicates the process average but it does not reveal the natural tolerances of the process. These tolerances may be calculated from the control limits on the chart, by means which are beyond the scope of this paper, or they may be judged from frequency distribution curves and cumulative frequency curves.

Discussion

John B. Veach, Jr. (Bemis Hardwood Lumber Co.): In the example which was used in this paper what is the probable significance of a point outside the control limits from the chart for averages.

Mr. Pratt: Average moisture contents are controlled by kiln operators through the use of samples. Averages

[3] Manson, B. C. "Application of Statistical Quality Control to the Seasoning of Lumber", Unpublished Memorandum, California Redwood Association, San Francisco, 1953.

(Continued on page 212)

TECHNICAL SESSION II—Mon., June 15, 1953, 2:00 P.M.

Subject: Glues and Gluing

Chairman: Alan A. Marra

Recorder: Howard Rosenberry

Production Gluing

RALPH CASSELMAN

Assistant to Vice-President, Paine Lumber Co. Ltd., Oshkosh, Wisconsin

While technical considerations are of first importance in gluing operations, these factors alone do not insure the best performance of the gluing department. Ideal conditions are so seldom reached that daily exercise of practical judgment is commonly necessary and anticipation of results from compromises is a very important responsibility. This paper discusses ways and means of getting best overall results from gluing formulas, facilities and personnel available.

THIS DISCUSSION is meant to assist in adapting the technical information available on gluing with synthetic resins to the requirements of production in the bonding of Eastern hardwoods. Its further purpose is to show how simple and reasonable methods of control in the glue room can effect worthwhile and measurable savings in plywood manufacture.

Those engaged in production gluing have available a tremendous amount of technical and promotional literature on how their operations should be performed. The straight production man, however, is not ordinarily a great reader of technical literature, and is not apt to have had the training or wide experience allowing him to separate from the field that which is useful to him. Neither does he commonly attend the technical sessions where the problems of the industry and their solutions are discussed. His principal contact is liable to be the sales representative with specific products to sell. And since the production man, usually the glue room foreman, is the channel through whom application techniques must flow, the full benefits of wood and glue technology are not always realized.

As a general procedure to improve this situation, we suggest a determined and widespread effort to translate the technical information into plant terms, to separate the academic from the directly useful and to place special emphasis on the education of production personnel. Consistent with this program is the encouragement of all concerned to deal directly and quantitatively in labor, material, and equipment costs without which the score cannot be kept.

As we begin to focus our attention on the operation of the glue room we find there are considerations other than technical which determine its successful operation. In particular, we wish to emphasize the requirements of vigilance, resourcefulness, and balance. Good gluing is obtained at the price of constant vigilance. A simple mistake such as omission of the catalyst can cost thousands of dollars. Hesitation in recognizing trouble in its early stage can compound an error into plant wide panic. Passing of poorly glued stock can ruin the company's hardwon reputation. Resourcefulness must overcome lack of uniformity in the wood or perfection in the equipment. Insistence on exact moisture content or dimension can stop production. Schedules must be met by constant practical compromise. Proper balance must be maintained between one procedure and another. The convenient, easy way may be the expensive way. While a heavier spread may solve the problems of delay in assembly, its cost should be balanced against some other method such as adding a man and saving the glue. The costs of delay may have to be balanced against the wrinkles in the faces, or the increased cost of spread against the variation in moisture content. But in each case judgment must be exercised. It is not enough to simply follow the most obvious way without regard for costs and consequences.

One of the most difficult problems to handle in the glue room is to anticipate the effect of compound variables. For instance in cold pressing, a slow mix might ordinarily be satisfactory but if the veneers are cold and dry and the mix slow, trouble is likely to ensue. A thin mix may do well on birch but when applied to rough basswood and, in addition, subjected to delay in assembly, it will cause dry bonds. In hot pressing, a thin spread of fast glue with fast assembly on one-sixteenth inch faces is very satisfactory, but a change to one-twenty-eighth faces compounded by a hold up in assembly can cost the press load of panels.

It goes without saying that the supervisory personnel in the glue room should be cost conscious, should know the value of the materials they handle, and have some idea what errors or negligence may cost.

A never ending problem in the glue room, as in other departments, is the extent of authority and responsibility. Too much supervision destroys initiative and too little allows runaway costs, yet both circumstances can frequently be found. We favor selection of supervisory personnel on the basis of competence, full training in their jobs and the maximum reasonable authority. Proper and live records should serve as the index of performance. Under this system the foreman would be given the type of glue and the range of extension, if any, but allowed to vary his formula within the range to suit his daily conditions. He might want to vary the water content, the amount of catalyst and the proportion of walnut shell flour to suit his cycle or his veneers.

The controls that are necessary are best applied at close range. By controls we establish limits beyond which the gluing should not be done without either correction or compensation. Recommendations for the application

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of controls often omit balancing their cost against their value. It is easy to say that the moisture content of veneers should lie between 8 and 10 and quite another thing to bring the stock to that range. Difficult controls are very discouraging to production. The phenolic film glue under ideal conditions produces excellent results but its use is limited because so few people are willing or able to work within the narrow range of limits required. Melamine resins, on the other hand, might be theoretically less durable but the actual bonds are uniformly high because of the glues adaptability to plant conditions and the much wider range under which satisfactory bonds can be obtained.

Considering, then, the cost of controls as well as their importance, we suggest the following as a guide for cold press bonding of panels with urea resins: (1) Minimum temperature of 70° F. in glue room and veneers. Heating is much cheaper than poor bonding. Cold drafts along the floor can be corrected. Veneers, if taken out of a cold storage area or freight cars should be held in a warm room (but not hot) or passed quickly through a low temperature dryer. (2) Maximum temperature of 100° F. for veneers including proviso that warm veneers are specially handled for fast assembly. The upper limit in the glue room will be set by personnel rather than gluing requirements. (3) Maximum limit of 10% moisture content on veneers unless some other limit is positively necessary. Veneers below 6% will require careful attention in glue formula, spread, and assembly. (4) Three-hour pot life on glue obtained by adjustment with catalysts to variations in conditions. (5) Glue mixed in batches of a size to be used up in 30 to 40 minutes. (6) Glue spread range 45 to 50 pounds per thousand feet of single glue line raised 5 pounds for occasional batch of dry veneers. (7) Upper limit of 12 minutes on assembly time, no lower limit. (8) Relative humidity in winter raised to 40%, no control in summer. (9) Press at 220 p.s.i. except for very soft wood. (10) No definite limit on glue temperature but keep on cold side. Use cold mixing water. (Water standing in pipes overnight should be run out as it may be warm.) (11) Spreader crew must be alert for variations in veneer thickness which their experience has shown are not allowable. (12) Bales kept under pressure for 6 hours minimum in warming room at 100–110° F. Unit heater should be used to prevent cold air stratifying at lower levels. (13) Check on bonding by frequent examination of trim and occasional panel. Wood failure should be adequate *immediately* after breakdown of bales.

The hot pressing equivalent of this procedure would place special emphasis on fast glues, short assembly time, moderately thin and uniform spread, short press time and press temperature of 240–245° F.

Controls and records are often resented when first introduced but become a right hand when established. In one case, weighing the spread was initially regarded as a nuisance and unnecessary on the supposition the operator could gage with his finger the right amount. It was found, however, that the spread varied from 36 to 69 pounds on this basis and various troubles including dry bonds and bleeding through the faces resulted. These were eliminated by holding the spread between 48 and 52 pounds weighed several times a day.

So much has been said over the years about assembly time that we hesitate to mention the subject. However, control of assembly time is the key to good, efficient, and economical gluing so can hardly be overemphasized. There are still those who try to compensate for overlong assembly in cold pressing by piling on the glue. For joint gluing this method may be helpful and not too costly, but for panel work the cost is inexcusable and the results unsatisfactory. It is far less expensive to take the steps necessary to hold down the assembly time. The measures might include building smaller bales, adding blocking, speeding up the spreader, shifting or adding to the spreader crew, or if high production is needed, feeding one press with two spreaders.

We observed a panel operation normally requiring a 45–50 pound spread where 60 were being applied to allow for erratic assembly time. By holding to a twelve minute assembly, the extra 10 pounds were saved and better panels produced. The only investment was an alarm bell which was paid for every hour.

Weighing Spread Saves

Weighing the spread is about the easiest way to save money in making plywood. It is regrettable that the practice is not universal. It is most likely to be done regularly when made easy. The easiest method we know is to eliminate calculation by using the proper size sample—318 sq. inches. The sample should be veneer of the same character as being spread and about the width across the spreader. A good size is 26″ long by 12¼″ wide fed cross grain through the machine. The sample is weighed on a gram scale before and after spreading. The difference is pounds per thousand square feet, single or double as spread. The gram scale can be obtained through office supply houses who order it from the catalogue.

Most recommendations for moisture content of veneers are too narrow for normal production. Fortunately good bonds can be and are obtained below the 6% minimum frequently specified. Heavier spreads, short assembly, and fast setting glues compensate for moisture content lower than the preferred minimum. Although raising the moisture content is considered clumsy and is mostly avoided, drying moist veneers is a more familiar procedure and a maximum of 10% not too difficult to handle.

Controlling Pot Life

We believe that in many gluing operations, pot life control does not get the attention it deserves. In cold pressing, and particularly where the clamping time is short, the pot life should be constantly checked and if necessary, adjusted. The resin manufacturers supply catalysts of different speeds or recommend varying proportions to control the pot life of the glue mix. But with apologies to the resin suppliers, we suggest that the plants using important quantities of urea resin buy their catalyst raw materials in the form of bulk chemicals as is done in the paper industry where similar resins are consumed in large quantities. This suggestion is based not only on the cost advantages which are appreciable, but on the benefits of simplicity in inventory and better glue control once the formulas are established.

A simple and easily handled catalyst or hardener system comprises three easily available and inexpensive chemicals, ammonium chloride, monoammonium phosphate and concentrated ammonia. The chloride serves for most common formulas, the ammonia acts as a retarder and the monoammonium phosphate as an accelerator or by itself as a fast catalyst. These chemicals can be used singly or in combination in both hot and cold pressing, and with all straight urea resins with which we are familiar. In a typical cold press plywood application the system works like this: For a normal temperature low extension formula with low solids resin, two pounds of ammonium chloride per 100 of resin are used. In the last batch before noon hour the glue mixer drops in one half pint of ammonia to keep the glue from setting on the rolls. When the room temperature

rises he lowers the chloride to one and one half parts or if extremely hot adds a little ammonia. When the glue room and the stock are liable to be cool he replaces part or all of the chloride with the mono-ammonium phosphate. He thus manipulates the formula to maintain a 3 to 3½ hour pot life except during the noon hour when a little more time is needed. Representatives of the resin suppliers are usually willing and able to help establish this system and small scale trials will develop sufficient familiarity to allow production runs. Better pot life control insures definite clamping time and maintenance of schedules as well as better bonds.

Catalysts for special purposes are not included in our recommendations.

Best assurance that the catalyst has been added and in the desired amount is obtained as follows: Weigh the catalyst for several batches or perhaps the days run into paper cartons. Then to each carton add a small pinch of water soluble dye such as malachite green. Preweighing the catalyst allows the foreman to check the weight and the dye lets the spreader crew know the catalyst is in the mix. Just before the catalyst is added to the batch it should be dissolved in part of the formula water.

Testing

Extended experience on many test methods has led us to the opinion that there is no substitute for prompt, frequent examination of the panel trim and occasional panels made immediately after releasing the bale from the retainers. It is necessary that any irregularities be observed while their causes are still traceable so they can be analyzed accurately and corrected with no delay. Admittedly a numerical index of quality would be very desirable but for production control we feel the small increase in measurability gained by shear strength and cycle tests is not worth the lapse of time. With high wood failure, the glue formula and the procedure should determine the further nature of the bond. We find also that reliance on improvement of the bond after "maturing" is a questionable practice with urea resins, as weak initial bonds may or may not improve. High wood failure immediately after pressing is a bird in the hand; a test necessitating delay is a bird in the bush.

We may speculate on the direct tangible benefits to be gained by exercising proper control over the most important elements we have discussed by comparing the plywood gluing operations of two imaginary competitive manufacturers, the Hypothetical Plywood Co. and the Parenthetical Plywood Co. The Hypothetical Plywood Co. has a daily schedule of 100,000 sq. ft. of 3/16 three ply hardwood plywood comprising five thousand panels of twenty sq. ft. each. In a well intentioned move for economy, the spreader and press crews are held a bit short and large bales of 180 panels each are built up. The assembly time is long and erratic, averaging 18 minutes, especially long if a crew member is absent for a while. A heavy variable spread averaging 56 lbs. per thousand single is applied (but not measured) to compensate for the long assembly time. A liquid resin of 60% solids is used with an extension of 30 parts of flour. The mix is richer than used elsewhere but set up on a defensive basis against non-uniform results. The standard proprietary catalyst is added at the rate of 4 parts per 100 of resin without special effort to control the pot life. Clamping time is, of course, extended on cold days. Cold veneers from the unheated storage shed are run occasionally. Split crossbands are run through the spreader and those in fair condition fitted into the lay-up, but about thirty each day at a dollar a piece are discarded after spreading. Bonds are checked only casually, mainly after trouble has developed.

Production is somewhat erratic but a large inventory of panels disguises the daily variations in output. Rejects, returns, degrade and cutdowns average 2% of value although a full record is not kept. Everyone in the department is busy in straight production and no-one is delegated to check the elements of control.

The overall results do not seem too bad as long as major crises are infrequent. General management is familiar with labor costs and they do not seem to be out of line. It is less familiar with other costs and they are given only perfunctory attention. Lacking confidence and the ability to anticipate the possibilities of improvement, management prefers to leave the status quo undisturbed rather than take what it believes to be the risks of change.

Now the Parenthetical Plywood Co. makes a similar product in the same amount from equivalent raw materials. But its operation has been improved now and then by paying closer attention to the fundamentals of resin gluing. Assembly is held to a twelve minute maximum by pressing only 100 panels in a bale and by having an extra man who takes the place of a missing crew member and who otherwise helps with retainer clamps and brings the veneers to the lay-up. The crew is well trained, working with a swing and impressed with the importance of maintaining production. The catalyst is adjusted with bulk chemicals to hold a uniform three hour pot life and the bales are retained in a warming room for six hours at 105° F. An assistant to the foreman measures the spread frequently holding it at 44 to 48 lbs., looks over the veneer loads for splits, warp, culls, thickness size and moisture content. He also keeps an eye on the assembly time, the gage pressure, the temperature and circulation of the warming room, and works with the glue mixer to adjust the catalyst. He inspects the trim of every bale and occasionally rips open a panel to examine the bond. He informs the foreman of irregularities in stock or conditions which require special handling. The rolls are regrooved as often as necessary to control the spread accurately.

Because of this close attention and consequent uniformity, the glue can be extended with 50 parts of flour and the desired quality maintained. Because of the reliability of the procedure, the losses from rejects and cutdowns are held down to 1%, carefully recorded and analyzed for correction.

Savings Justify Careful Glue Control

To see whether the extra effort applied by the Parenthetical Plywood Co. is worth while we can compare the indicated cost differences.

(Continued on page 214)

	Hypothetical Plywood	Parenthetical Plywood
Production, per day average	100,000 sq. ft.	100,000 sq. ft.
Average panel size, sq. ft.	20 sq. ft.	20 sq. ft.
Production labor—spreading and pressing crew	11 men	12 men
Assistant to foreman		1 man
Cost of labor per day	$125	$150
Number of bales per day	28	50
Assembly time—average	18 min.	10 min.
Assembly time—maximum	24 min.	12 min.
Flour extension (60% urea resin)	30 lbs.	50 lbs.
Glue spread	56 lbs. per M	46 lbs. per M
Glue cost per lb. wet mix	$.068	$.059
Glue urea per day, wet mix	11,200 lbs.	9,000 lbs.
Glue cost per thousand sq. ft. single spread	$3.81	$2.72
Total glue cost per day	$762.	$543.
Catalyst	4 lbs. Proprietary	2 lbs. Ammon. Chloride
Catalyst cost per 100 lbs. of resin	$.48	$.14
Catalyst cost per day	$32.16	$9.40
Cost of discarding spread cross banding	30 @ $1. = $30	6 @ $1. = $6
Cost of returns, rejects, degrade, cut downs	2%—$300 per day	1%—$150 per day

The Gluing of Preservative-Treated Wood for Severe Service Conditions

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Glueing of preservatively treated lumber promises to extend the use of wood. Authors review developments, describe current uses and list some tests and specification that currently govern production of preservatively treated, laminated products.

THE DEVELOPMENT of fully waterproof adhesives permits the use of glued wood materials under all conditions of service, although much yet remains to be done in the development of adhesives to make the process of gluing for severe service conditions more economical. There are available on the market today adhesives which can be used to glue veneers and lumber into products for outdoor service with definite assurance that the glue will be completely durable. Although the glue lines can be expected to last indefinitely, the use of wood in certain structures is now limited by its inherent lack of resistance to decay. Some woods are more durable than others, but all of the American commercially available species will rot under certain conditions. In many products this is now the limiting factor.

Laminated members in ship and boat construction, bridge timbers, docks, telephone poles, mine timber, are but a few examples where wood, whether it is glued or not, is susceptible to severe decay hazard. In ships and boats particularly, the initial expense of construction is high and the ultimate durability of the ships is of tremendous importance. Data kept by the Navy on various hulls constructed during World War II show that in many instances only 7 to 10 years service life was obtained. The Navy would like to have their wooden ships last thirty years or more. This objective can be attained only through the use of wood that has been treated with a suitable preservative.

There are two ways in which a glued-up assembly can be made toxic to decay organisms. The first is to treat with preservative after the member has been glued up; the second is to treat

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Figure 1.—Hull of AMS type minesweeper with steam-bent white oak frames in place. Pressure treated red oak, laminated into straight members which are subsequently steam-bent to form the frames are now being produced which will substantially extend the life expectancy of this type ship. (Official photo U. S. Navy)

Figure 2.—Superstructure of this modern wooden minesweeper is sheathed with pressure preservative treated plywood to prolong the service life and reduce maintenance costs. All plywood in the Navy's new ships and boats is preservative treated. (Official photo U. S. Navy)

the veneer or lumber and subsequently to glue the treated material to desired shape and size. Each method has its place and is currently used, but the problems involved are substantially different. It is the purpose of this paper to point out the procedures which have proven to be successful for the two methods of treatment.

Some work has been performed on the gluing before and after treatment with adhesives other than of the synthetic resin type. However, the principal efforts in gluing of treated wood were made after the fully waterproof resins were developed, since there was little reason to make glued wood resistant to decay if the glue lines would not withstand the service conditions under which decay usually occurs.

Mention is made in ref. (4) of the possible protection by suitable preservative treatment of laminated timbers and the need for further development of the process. Some early pilot-plant tests were conducted on the preservative treating of laminated Douglas fir, southern pine, and white oak (6).

Preservative and fire retardant treatments are recognized as being applicable either before or after gluing, depending on the compatibility of the glue and various chemicals used (7).

It has been conclusively proven that when thoroughly cured, certain synthetic resin adhesives are not damaged by pressure treating of glued products either with a water-borne or oil-borne preservative. On the basis of early studies the pressure treatment of plywood and laminated structures of a shape suitable for insertion into a treating cylinder has become common practice.

There are many applications in which glued-up members are used where treatment after gluing is not practical. This may be due to the economics of shipping the members to a treating plant or because the size and shape of the glued-up assembly is such that it is not practical to treat after gluing. The development of methods or techniques of gluing treated wood was the answer to the foregoing problem. Several laboratories worked on this problem and from the results of this work have evolved methods which make the gluing of treated woods a practical reality. Shipbuilders also recognized early in the development of laminating the advantages of fire retardant treatments for fireproofing lumber before laminating. The Puget Sound Naval Shipyard explored this field in 1947 (10).

Through the use of preservative-treated wood, the available supply of lumber for use under extreme service conditions can be greatly expanded. The natural durability of the wood species becomes of minor importance when the wood is treated with a suitable preservative. This means that species currently considered not suitable for severe service conditions will become acceptable. A good example of this condition is in the current Navy wood shipbuilding program in which white oak is used extensively for major structural members. Through the use of preservative-treated red oak, which has practically the same strength properties as white oak, the available lumber supply can be greatly expanded. The use of red oak would potentially add about two billion board feet of lumber per year to the shipbuilding program. Other species which are not currently used in the shipbuilding program would also be available since, with proper preservative treatment, they will be perfectly adequate for this end use.

Development of Treating Procedures for Subsequent Gluing of Wood

There are a number of preservatives which will adequately protect wood from decay and which are being used in commercial treating operations. The first step in the development of the methods of gluing treated wood was the selection of the preservatives which are compatible with currently available adhesives.

Work done in different laboratories as well as practical experience by users and recommendations by the wood treating industry (12) resulted in the selection of preservatives and retentions for use in marine laminated structures as shown in Table 1.

While the data shown in Table 1 refer specifically to oak, Douglas fir and mahogany plywood, there is no reason why identical retentions for other treatable species could not be adapted for use both in marine construction and for exterior use. Where the glued members are to be exposed to direct contact with the ground, higher preservative retentions may be necessary. Research is also under way in the treating of veneers prior to gluing. It should be emphasized that the retentions shown in Table 1 for protection against marine borers are intended for use on high speed hulls which receive periodic applications of anti-fouling paints. They should not be used for shore installations and similar uses.

Table 1—PRESERVATIVES AND RETENTIONS SPECIFIED FOR PROTECTION OF LUMBER (2) AND PLYWOOD (3) FROM DECAY AND MARINE BORERS FOR MARINE SERVICE

Preservative	Protection of lumber from decay: Minimum net retentions and concentrations Lbs. per cu. ft.	Protection of plywood from decay: Minimum net retentions Lbs. per cu. ft.	Protection of lumber from marine borers: Minimum net retentions and concentrations Lbs. per cu. ft.
Acid copper chromate (Celcure)	0.75	0.50	1.50
Ammonical copper arsenite (Chemonite)	0.45	0.30	1.50
Chromated zinc chloride (CZC)	1.15	0.75	----
Copper naphthenate	6.00 (2.0% metalic copper by weight)	----	10.00 (2.0% metalic copper by weight)
Pentachlorophenol	6.00 (5.0% solution)	----	----
Tanalith (Wolman salts)	0.55	0.35	----
Green salt (chromated copper arsenate)	----	0.50	----

It will be noted that some of the preservatives listed in Table 1 are water-borne, while others are oil-borne. The physical and chemical characteristics of the treated lumber as related to subsequent gluing depend on the type of preservative used.

Experience to date has shown that, in order to glue wood satisfactorily, its moisture content should be below 20 percent, although current development work indicates that wood at a moisture content above 20 percent may be successfully glued. Because of the current 20 percent requirement, lumber treated with a water-borne preservative must be re-dried to a uniform acceptable moisture content before it can be glued. Either air-drying or kiln-drying can be used, depending on the available time between gluing and treating. Once the moisture content of the treated wood has been reduced to the required level, the chemical retained in the wood from the common water-borne preservatives does not particularly interfere with the gluing operation (5, 13).

When oil-borne preservatives are used to treat wood to be glued, no significant change in the moisture content of the wood occurs during the treating process. Since oil-borne preservatives can be carried in various grades of petroleum solvents, it is important that a suitable grade be used. During the development of the technique for gluing oil-borne preservative treated wood it was at first considered essential that as much of the carrier as possible be removed from the wood before gluing was attempted. Later work has shown that this requirement was not as critical as believed earlier; this subject will be discussed in more detail later.

Many of the fully waterproof adhesives currently in use for the gluing of wood for exterior service conditions are compatible with the chemicals used in oil-borne preservatives. Special care, however, must be exercised in selecting an adhesive which has been evaluated for this purpose. Both laboratory and production experience has shown that certain formulations of fully waterproof glues which are excellent for the gluing of untreated wood do not give good results when used on treated wood.

All the tests reported in this paper are based on the pressure impregnation of the wood with preservative. Generally speaking, this is the safest method for the application of preservatives for all types of structures particularly parts of wooden ships which are subjected to framing operations following the treatment. Cut surfaces, however, should be liberally brush coated with preservative after framing has been completed. Thus, under some conditions, non-pressure treatment may be recommended.

Figure 3.—All-wood military truck body of modern design. This prototype body was built by the lumber industry for the Ordnance Department out of pressure treated gum and oak. Every glue joint is made with a fully waterproof resorcinol adhesive.

Bundle Dipping

Recent experiments have indicated phenomenal penetrations of oil-borne preservatives in some of the easily treated woods. These studies have been made by bundle dipping in the preservatives for periods of up to ten minutes. Although practically 100 percent penetration throughout the bundle and throughout all the wood in the bundle was obtained in these experiments the amount of preservative picked up by the wood was considerably less than the amounts normally recommended for uses where severe decay and marine borer hazards exist. No recommendation for the use of such dip treatments have been made beyond the fact that they appear to be suitable for lumber that is to be bulk-piled and stored before use.

Preparation of Surface of Treated Wood for Gluing

In the commercial methods of treating wood, particularly the refractory species, the greatest concentration of preservative is usually located at or near the surface of the board. Because of this condition, it is important to keep the amount of surfacing to a minimum after treatment. It is desirable, therefore, in order to achieve maximum protection from decay, to treat rough-surfaced lumber and to allow just enough additional thickness of wood so that finish-planing necessary to produce good gluing surfaces can be accomplished after treatment.

As in the surfacing of untreated wood, high standards of accuracy are required for the surface preparation of preservative treated woods for gluing. For example, it is required that tolerances of plus or minus 0.005 inch be the maximum allowed in the preparation of material for ship timber lamination. Some commercial practice allows a somewhat larger tolerance. Whatever the specifications require, however, the smaller the deviations in thickness of the individual laminations, the better will be the gluing job.

In laboratory as well as commercial studies preservative treated wood has been adequately surfaced without noticeable dulling effects on the knives of the planer or jointer. Of course, it is necessary to periodically clean the machines to remove preservative materials which may accumulate. No studies have been made to determine whether knife changes will produce superior results. Current practice indicates, however, that entirely satisfactory surfaces are prepared with conventional knife settings in planers and jointers.

One of the most important problems in the development of techniques for the gluing of treated wood was defining the time limits between surfacing and gluing. Federal specification MIL–W–17445 (2) for the gluing of pressure-treated oak for marine use stipulates the following:

Table 2—RESULTS (5) OF BLOCK SHEAR TESTS OF RED OAK TREATED WITH PENTACHLOROPHENOL AND GLUED WITH ONE PHENOL-RESORCINOL ADHESIVE AFTER VARIOUS PERIODS OF TIME AFTER SURFACING[1]

Period between[2] preservative treatment and surfacing	Time between[3] final surfacing and gluing	Preservative retention Lbs. per cu. ft.	Maximum shear stress PSI	Wood failure Per cent
1 day	15 minutes	6.4	2705	84
1 day	4 hours	6.7	2756	82
1 day	4 hours	9.9	2769	77
1 day	15 minutes	13.9	2702	89
1 day	4 hours	15.7	2210	93
5 days	10 minutes[4]	16.9	1845	100
7 days	2 minutes	15.2	1943	92
9 days	30 minutes	10.5	1996	98
7 days	1 hour	14.5	2152	100
31 days	3 days	20.4	1964	100
30 days	Not surfaced after treatment	21.3	2034	95

[1]The glues were cured at 150° F at the glue line for 10 hours.
[2]Boards were stickered during period between preservative treatment and surfacing.
[3]Boards were stickered during period between surfacing and gluing.
[4]These billets were surfaced 10 minutes before gluing and wiped with a rag about 2 minutes before gluing.

"The final surfaces for gluing shall be prepared not more than 24 hours before gluing is started where waterborne preservatives are used and not more than 8 hours before gluing where oil-borne preservatives are used".

The foregoing limits have proven to be practicable for production gluing. The principal reason for the lesser time permitted between surfacing and gluing of wood treated with oil-borne preservatives is the tendency of the solvent to migrate to the surface, and thus a greater contamination of the wood surface to be glued is possible. There also exists a possibility that oil migrating to the surface may interfere with bonding. Results of exploratory work on this problem indicate, however, that the presence of oil within certain limits on the surface to be glued may not be as serious as it was first thought.

To study some of the variables in time permitted between treating, surfacing, and gluing and the effects of different retentions of preservatives, a series of block shear tests on pentachlorophenol-treated and subsequently glued red oak were performed. These results, shown in Table 2, are applicable only under conditions indicated; other adhesives and curing conditions may produce less satisfactory results.

Curing of Glue in Treated Wood Assemblies

As in the gluing of untreated wood, the selection of an adhesive and a curing temperature to be used with treated wood is dependent to a large extent on the service conditions under which the end product will be used. Under severe service conditions, the principal cause of delamination stems from shrinkage and swelling stresses exerted by adjoining layers of wood on the glue lines. The amount of these stresses is dependent upon the range in moisture content in the adjoining layers of wood, the density of the wood, and the thickness of the individual wood layers. It is assumed, of course, that an adhesive is selected which produces a desirable waterproof bond.

In the initial development of techniques for the gluing of wood treated with the preservatives listed in Table 1, it was considered necessary to use curing temperatures higher than those recommended for untreated wood. Subsequent research revealed that this limitation was not essential for the particular brands of water-proof adhesives used and that while slightly greater percentages of delamination were obtained with treated wood than with untreated wood when glued under identical conditions, the resulting joints were satisfactory in all respects as defined by the current military specification.

While the whole range of time-temperature schedules suitable for the gluing of treated wood has not yet been completely investigated, certain schedules have been developed which produce satisfactory joints; these are shown in Table 3.

Table 3—BLOCK SHEAR AND DELAMINATION RESULTS OBTAINED FROM TREATED RED OAK, SOUTHERN YELLOW PINE, AND DOUGLAS FIR GLUED WITH A PHENOL-RESORCINAL ADHESIVE[1]

Preservative	Species	Block shear test: Average retention Lbs. per cu. ft.	Block shear test: Maximum shear stress PSI	Block shear test: Wood failure Per cent	Delamination Per cent
Tanalith	Red oak[2]	0.53	2402	90	0.1[4]
Celcure	Red oak	2.09	2294	84	3.6
Pentachlorophenol	Red oak	11.30	2271	76	2.2
Greensalt	Red oak	2.05	2041	89	2.3
Copper naphthenate	Red oak	10.50	2472	78	3.4
Copperized chromated zinc chloride	Red oak	2.45	2214	86	1.9
Tanalith	So. yellow pine[3]	0.56	1833	79	1.3
Celcure	So. yellow pine	2.11	1757	72	5.2
Tanalith	Douglas fir	0.60	1445	78	1.3
Celcure	Douglas fir	2.36	1305	91	1.5

[1]These tests were performed for the Bureau of Ships at the Forest Products Laboratory(14).
[2]The curing schedule used for the gluing of red oak with all the preservatives shown was cured 9 hours at 150° F at the innermost glue line.
[3]The curing schedule used for the gluing of southern yellow pine and Douglas fir with the preservatives listed was 8 hrs. at 120° F at the innermost glue line.
[4]These results were obtained on the basis of the 12-day cyclic delamination test as specified in A.S.T.M. D-1101-50T.

Low Health Hazard to Humans

Safety to humans in handling preservative treated timber as well as working near treated wood is particularly important with ships and other structures in which personnel work or live. Very few actual tests have ever been made to determine the influence of preservatives upon the health and comfort of persons in close and continuous contact with the preservatively treated wood. However, there are many practical instances which show that working near preservatively treated wood does not constitute a hazard. It is reported, for example, that the drinking water of some localities is actually carried to the city in preservatively treated wood-stave pipes (8).

Even preservative materials containing small amounts of the toxic chemical, arsenic, have been safely used. Large quantities of compounds containing arsenic have been used in the treatment of wood and fiber board with no apparent ill effects on those who have processed the material or those who lived in structures made from it.

Occasionally, contact with preservatives as well as synthetic resin adhesives will cause dermatitis. However, there are no records of dermatitis developing from either properly cured glues in the glue joint or wood that has been adequately seasoned after treatment with a clean preservative. Furthermore, freshly treated wood is safely handled by a great many people without serious discomfort.

Some concern has been expressed about the possibilities of ill effects on humans confined in small spaces completely surrounded by treated wood. It is true that freshly treated wood under such conditions might cause some objectionable odors but it is unlikely that any serious health hazard will be encountered in most structures; the period of time between treating annd installation in structures where treated wood is used will usually be great enough to permit dissipation of those volatile parts of the preservative or carrier which might cause discomfort to humans. In most instances the treated wood is painted over.

In some recent tests with copper naphthenate and pentachlorophenol, sheep and other animals were actually drenched with 5 percent solutions of one or the other preservative. Others were fed from troughs which had been impregnated with the preservative. None of the livestock studied in these tests showed any visible effects from being confined in treated structures or obtaining their food from treated troughs. Surprisingly, none of the animals showed any visible affects from the drenching with preservative material (15).

Future Developments in Gluing Treated Wood

The wood using industries will find many new uses for products made possible through gluing preservatively treated wood. The number of species available for uses where decay or insect hazards are high is tremendously increased. The improved service life of wood under conditions of rapid deterioration will enhance its utility. The better service performance will make wood of greater interest to the prospective customer. Thus, wood is placed in a better competitive position for many special types of construction because of its longer life and hence reduced annual cost.

Only a few specific uses are mentioned here; all are now in various stages of adoption. The use of preservatively treated and glued timbers is already making headway in naval vessels and is expected to be a stimulant to the construction of commercial wooden vessels.

Following World War II, military authorities were emphatically opposed to the use of wood in military truck bodies. One of the reasons for this objection was the reported rapid decay of the wood. Now that wood can be treated and laminated, interest in all-wood truck bodies has been aroused and three proto-types designed and built by the Timber Engineering Company are now being tested by the Military (11). Authorities have expressed amazement that no failures had occurred in these bodies during the first few weeks of rugged testing.

Cross ties are replaced at the rate of 40–50 million ties per year. About half of the hardwood ties are replaced because of splitting and checking. Laminated ties should nearly eliminate this type of failure. Through and through treatment made possible by preserving before laminating, will assure railroad engineers that neither aging nor tie plate wear will expose untreated wood to attack of fungi.

Preservatively treated lumber glued up into sizes 12″ x 12″ and larger will help retain lumber's large market in keel blocks. Nearly 150 laminated keel blocks have been in service over a year. All are still in service; most are still in "excellent" condition (1).

Through the development of the technique for gluing treated lumber it is now possible to supply the shipbuilding industry with preservative treated laminated straight pieces which can be subsequently steam-bent to the desired contour. Small quantities of such material have already been produced (5).

Many further improvements in techniques of gluing preservatively treated wood are still needed. Among the more important of these procedures is the development of ways to reduce the loss of preservative when the lumber is surfaced following treatment. In most processes of preservative treatment, a high percentage of the preservative material is near the surface; thus when the lumber is given the needed surfacing prior to gluing, that preservative located in the material removed by the surfacer is lost. Possibly procedures for reducing the concentration of preservative at the surface can be developed through improved impregnation techniques or perhaps by some process such as the solvent recovery procedure.

Through many years of experience and testing, the treating industry has developed recommendations for the amount of preservative required to give adequate protection to solid lumber. This whole field should be reopened in the case of preservatively treated lumber that is glued-up. Possibly the more thorough penetration that is obtained by gluing treated wood may permit decreases in the actual amount of preservative in the wood. On the other hand, it could be argued that with the greater distribution of the preservative throughout the built-up piece, a larger amount of preservative would be required. There are many authorities in the field who believe that penetration is more important than absorption except possibly for marine borer exposures. If this can be borne out by tests of laminated timbers, the absorption rates can be reduced slightly and still give entirely satisfactory performance. This should be thoroughly and carefully studied!

In the most recent design of wooden ships, working stresses have been used that are greater than current commercial standards (9) with the introduction of preservatives, eliminating the strength losses due to decay, it is possible that preservatively treated and laminated timbers of all sorts could be given higher working stresses.

At this time, the process of gluing treated wood has not been adequately tested for all of the water-proof adhesives and all of the wide variety of commercial preservatives available. This is a field that many investigators should consider as one worthy of their efforts and offering the possibility of fruitful results.

The present specifications (2) requires that suppliers of glued treated oak ship timbers have qualification tests made on the basis of each preservative treatment and each type of adhesive.

The influence of glue-curing temperatures on preservatives should be investigated. Temperatures used in curing some glues particularly in a hot press are high enough to cause volatilization of some preservative materials. Preservative manufacturers and glue producers alike should know the limits of both the preservatives and the glues in this respect.

The effect of steaming on the toxic characteristics of preservatives used in laminated blanks for ship construction should be studied. Little is known about this subject because of the newness of the use of preservative treated wood.

Only time will fully disclose the true and complete significance of this recent development—the gluing of preservatively treated lumber. It is certain that it will extend the uses of wood and will provide the consumer with better wood products.

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Discussion

Mr. Selbo (Forest Products Laboratory): In table I the retentions of preservative is lower for plywood than for lumber. What is the reason for this?

Mr. McKean: I am not certain about the reason.

Mr. Selbo: In table II, as retention increases the shear strength decreases. Do you have any explanation for that?

Mr. McKean: High retentions may affect strength.

Mr. Selbo: For what uses would you consider gluing at 20 percent moisture content desirable?

Mr. McKean: In connection with steam bending tests made at 20 percent; moisture content was not found as important as range in individual pieces.

Mr. Selbo: You do not show any results for untreated controls. Did you include controls?

Mr. McKean: Major emphasis is to conform to Navy specifications as end control.

J. A. Greenwald (Cuprinol Division, Darworth, Inc.): Gluing treated lumber should increase uses for wood.

B. C. Williams (Norfolk Naval Shipyard): What's the story on wood truck bodies?

Mr. McKean: They are currently undergoing most severe tests and standing up well.

Harold E. Worth (Bureau of Ships, speaking for John Kuenzel): In this paper, the authors have summarized the general development of techniques for gluing treated wood and have indicated that a large part of the research on these methods has been sponsored by the Navy's Bureau of Ships.

It may not be immediately apparent to the reader just why, in this age of steel ships, the Navy should be concerned with better means of preserving wood. The reason is this: wooden ship and boat building is undergoing a renaissance to the tune of about a billion dollars worth of construction.

In this case, wood has not been used as a "last resort" substitute, which has so often been the case in the past, but has been chosen for essential characteristics which are not offered by other readily available structural materials.

The sizes and grades of timber, formerly used in shipbuilding, are no longer available in quantities sufficient for a large construction program. Laminated construction has done much to eliminate this problem, but ship designers have still had to rely on decay-resistant woods and be satisfied with something less than the best in expected service life.

Due to the size and shape of most boat and ship parts, preservative treatment of the finished member in a pressure cylinder is impractical. The best treatment to date has been the brushing or soaking of members with preservative. The Navy does not consider this good enough to provide the 30-year service life which it is shooting for.

With this information in mind, the advantages to the Navy of gluing treated wood are immediately apparent. Ships would have a longer life with lower maintenance costs; thoroughly preservative treated members of almost unlimited size could be fabricated; and many non-durable species, not now acceptable for boat and ship building could be used. Such improvements make sense to the Navy and appeal to us all as taxpayers.

The Navy is genuinely enthusiastic about the gluing of treated wood for shipboard use, and expects to incorporate this technique in future designs if pilot trials prove that laminated treated wood is durable under the severe exposure encountered in marine use. A few installations of glued treated members have already been made, and the performance of these installations will be closely checked.

It has been pointed out that the Bureau of Ships has recently prepared a tentative specification for laminated preservative treated oak. It is believed that this specification will provide members which are substantially equivalent in quality to the laminated white oak now being produced under Navy specifications.

This specification is based almost entirely on laboratory results, however, and has yet to be proven in large-scale production. A critical process of this nature obviously requires exacting control during manufacture, and demands that the producer be qualified in all respects for such work.

In order to be certain that a producer has such qualifications, the Navy requires a survey of facilities and laboratory tests of the product prior to production.

Besides general acceptability, the qualification test determines whether the adhesive and preservative, which the laminator has selected from those approved by the Bureau, are compatible under his particular laminating conditions.

A qualification test such as this, followed by close process control, good inspection, and adequate testing, provides a sound basis for producing high quality boat and ship members.

Techniques for Bonding Metals and Plastics to Wood

JAC. H. TIGELAAR

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The bonding of such dissimilar materials as metals and plastics to wood has developed into a significant volume of business. The number and types of adhesives being used for these applications are numerous and increasing. Several types are listed. The techniques considered of importance in making commercially acceptable products are discussed.

At the First National Meeting of the Forest Products Research Society held in Chicago in 1947, the author presented a paper entitled "Metal to Wood Bonding". Since that time, products involving the use of these two types of materials have been produced in an ever increasing amount and variety. Adhesive manufacturers have spent much time and effort in developing better materials. There have been improvements in the resultant products and processes, although the basic principles have not changed. Perhaps the most generally known application of the principles of metal to wood bonding is the making of structural sandwich panels in which the faces are of sheet metal and the core of a lower density material, such as plywood, lumber, paper, fabric or metal honeycomb, or various insulating materials.

To those in the woodworking industry who are acquainted with the problems encountered in making laminates of veneer or lumber, it is quite apparent that a product having metal or plastic bonded to wood presents these same problems, as well as many others. It is the intent of this paper to consider these problems, endeavoring to present some practicable solutions.

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Basic in the consideration of these problems is the answer to the question, why do certain chemical materials hold together critical surfaces? Or, in other words, why are certain chemical materials called and used as adhesives? We must, therefore, first of all, give consideration to the underlying causes or major factors of adhesion. Without becoming extremely technical, it is generally recognized that there are two types of adhesion, both of which function to a greater or less degree whenever materials are held together by an adhesive.(13, 14)

A) Mechanical adhesion which involves the interlocking of two surfaces, such as wood and glue. This is essentially what happens when bonding together two layers of wood with a liquid casein glue. Here the glue wets and surrounds the wood fibers at the surface first, and then as it gells and finally sets hard due to chemical action and loss of water, the glue holds the two layers of wood together. A film or powdery layer of the same glue, if placed between layers of the porous wood in the dry condition, would not bond them together because the adhesive and the adherent have not been mechanically united.

B) Specific adhesion which involves certain interatomic and intermolecular action between adhesive and adherent. An example of this type of adhesion might be demonstrated by placing together two very smooth and flat sheets of plate glass which were wet with water. Considerable force would be necessary to pull these apart. Here the thin film of water would be serving as the adhesive, and, for all practical purposes, the bond is not the result of mechanical adhesion.

Another factor, relating to the problem of specific adhesion, deals with the attractive forces between atoms and molecules. Much work has been done in this field by N. A. de Bruyne. (8, 9, 10) He describes these electrical forces as polar and non-polar and has shown that in order to get a strong bond, the adhesive and the adherent should both be either polar or non-polar.

If, then, as some authorities hold, the major part of the strength of an adhesive bond is due to specific adhesion and if the polarity and non-polarity of the adhesive and adherent are significant factors, it becomes apparent that in bonding together metals which are non-polar to wood which is normally strongly polar there are some very important problems to consider.

The author is not qualified to decide just how far it is possible to carry the principles of this latter theory of adhesion insofar as it relates to the subject matter of this paper. Suffice it to say that with our increased knowledge of the forces which play a part in adhesion of similar as well as dissimilar materials, the industry is continually improving the quality of bonds between metals and wood and plastics and wood.

In the previous paper, (16) the basic reasons for making a product having metal bonded to wood were discussed. We will now endeavor to present the techniques being employed in the industry in producing such products. It should be borne in mind that there is no universal adhesive as there is no one specific product employing a combination of metal and wood which meets all the needs of our complex civilization. Performance and service factors determine the selection of the best adhesive for each application. Associated with this is the economical practicability of the resultant product.

Preparation of Surface

A prime requisite in bonding together two materials is that the surfaces be properly prepared. The metal

or plastic surface must be free from oil and grease, and in the case of the former, also free of loose oxides. Where bonds of the best quality are required, it is significant to note that finder marks on the metal surface cannot be tolerated. Even a surface which is normally considered clean for paint adhesion may not be clean enough for a good glue bond. Ordinary vapor degreasing of sheet metals may not result in a satisfactory gluing surface. Chemical cleaning is generally considered very desirable.

In order to obtain greater advantage of the so-called mechanical adhesion characteristics of the adhesive, it is beneficial to roughen the surface of the non-porous metal or plastic. This can be accomplished by abrading the surface with emery paper, sandpaper, metal wool, sand-blasting, etc., after which the surfaces should be washed and wiped to remove all dust particles. When water is flowed over an adequately cleaned metal surface, it will form a continuous and unbroken film. This is a simple and practical test. A rather common method of roughening the surface of an aluminum sheet is to chemically treat it with an alkaline type cleaner. A deep etch can be obtained by using a caustic soda solution. It is necessary with this type of etchant to be sure to neutralize subsequently the alkali with an acid, such as chromic or nitric.

Army Air Force Specification 20032 "Process for Cementing Metal to Metal and Metal to Wood"(2) describes in detail methods for cleaning aluminum alloy, plain carbon steel, and magnesium surfaces. The following is the specified method for cleaning aluminum alloy surfaces:

> "Aluminum alloy surfaces shall be cleaned by immersing the parts in a cleaning bath, rinsing in running water, followed by immersion in a chromic acid bath.
>
> The parts shall be immersed in the cleaning bath, maintained at a temperature of 160 to 185 degrees F. for a period of three to five minutes. The composition of the cleaning bath shall be as follows:
>
> Sodium Metasilicate (Anhydrous)—3.6 ounces
>
> Alkyl Aryl Sodium Sulphonate—0.4 ounce
>
> Tap Water—1.0 gallon
>
> After removing from the cleaning bath, the parts shall be rinsed in running water and the surfaces examined for discontinuity of the water film. If the water film is discontinuous, the parts shall again be immersed in the cleaning bath, as specified above, and rinsed. The cleaning and rinsing shall be repeated until the water film maintains its continuity.
>
> The parts shall then be immersed in the chromic acid bath, maintained at a temperature of 140 to 160 degrees F. for a period of one to three minutes. The composition of the chromic acid bath shall be as follows:
>
> Chromic Acid—5 percent by weight
>
> Tap Water—95 percent by weight
>
> After removing from the chromic acid bath, the parts shall be rinsed in cold running water and dried with compressed air."

The above method has found rather general usage in the industry, especially if the bright mill finish of the metal sheet was to be retained. If an etched surface is permitted, then a stronger caustic replaces the sodium metasilicate. Anodizing, if not too expensive for the application, further enhances the quality of the product. The chromic acid process is considered superior to the sulfuric acid process.

Magnesium is one of the newer metals being used in making of structural panels in combination with wood and other core materials, such as paper honeycomb. This metal tends to very readily form an oxide coating on the surface. Special processes have been developed for protecting the surface and giving a good surface for painting and adhesive bonding. (4)

Because of the natural corrosion resistance of zinc coated steel, this metal has been used rather extensively in making metal faced plywood panels. A plain galvanized sheet does not give a paintable surface; neither is it satisfactory for gluing. It is necessary to give the zinc surface a chemical treatment. A phosphate type coating is commonly employed. Electrolytically deposited zinc on the surface gives a much better surface although even this is frequently given a phosphate type treatment. The latter is especially beneficial from a corrosion resistant consideration when the metal to wood bond is made with some of the cold setting type adhesives to be discussed later.

It is not practicable to chemically roughen the surface of stainless steel, so the general procedure is to clean it with solvents, and if an improved bond is desired, a mechanical roughening is given to the surface.

There are many companies who specialize in furnishing equipment and chemicals specifically designed to give sheet metals a surface satisfactory for painting. The general opinion seems to be that if the surface is of such a nature so as to give good paint adhesion, it will also be satisfactory as a gluing surface. This is not necessarily true. It can be readily demonstrated that with a protein-latex type adhesive, a so-called clean, smooth aluminum alloy surface does not give as good a bond as a surface also roughened by chemical etching or mechanical sanding. Tensile shear tests or peel tests made in the normal dry condition may not show this difference. Specimens soaked in water for one or more days and then tested show a marked difference in favor of the roughened or etched surface. This condition obtains also with the cold press rubber cements but is not nearly so evident with the less wettable hot press synthetic resins.

With respect to the preparation of the surface of plastics, some generalizations can be made. The more rigid and generally considered thermosetting type plastic sheets should be roughened by sanding or similar means. Recently developed equipment involves the use of brushes, which is economically practicable for surfacing plastic sheets (melamine, phenolic and polyester treated paper or fabric). The machine also gives a good surface to aluminum.[a]

Wood surfaces generally require no specific preparation, except that they be free from oil, grease and other foreign material. In the case of plywood which has been pressed at high temperatures and pressures, it is desirable to sand the surface lightly.

The scope of this paper is not intended to include or consider the more flexible and thermoplastic sheets, such as vinyl, cellulose acetate, polyethelene, etc.

The bonding of metal to wood can be divided into two general categories, as based upon general gluing procedures. The first is the so-called cold press or room temperature method, which, as the name implies, requires the use of cold-press gluing equipment and techniques. The second is the hot press method, which requires some means of heating the assembly while under pressure.

The quality of glue bond needed in the final product, as well as the cost which can be tolerated and the equipment available, determine, to a great extent, the specific adhesive which will be used and the method of making the bond. For normal com-

[a] Fuller Brush Company.

mercial applications, it is generally assumed that the cold press methods are most practicable. With the great increase in number of hot presses available, as well as the improvement in temperature, pressure and other operating controls, this assumption is becoming less correct with the passing of time and the developments in adhesives.

The cold press methods generally are less expensive primarily because the equipment is more simple. Because of the great difference in the coefficients of expansion of metal and wood, there are many practicable difficulties in making a flat panel when bonding by the hot press method. As the required bonding temperatures increase, the stresses on the glue lines also increase when the final assembly is brought back to normal temperature. A common procedure when using temperatures above the boiling point of water is to cool the assembly while under pressure. In the case of a steam heated platen press, this can be done by cooling the platens with water. In the case of applying a metal sheet to one side of a plywood panel, one cannot expect to get a flat panel by the hot press method. For a balanced panel (metal on both sides), this difficulty is not as great.

The hot press method, however, may, in general, be considered to give a glue bond of higher quality. Where glue bonds are required which possess such properties as high water resistance, good aging characteristics and extremely high strength properties in peel, shear and flexibility, this general method can be expected to be adaptable.

The author believes that one of the most important factors to consider when bonding metal to wood for the more common commercial applications is the corrosive characteristic of the adhesive. It can be demonstrated that a sheet of aluminum or zinc coated steel will corrode much more quickly in the area where it is in contact with wood (no specific species) than where it is in contact with only the humid atmosphere.(1) Because of this condition, the adhesive should be preferably a non-electrolyte and also not wettable with water after cured or set. For certain structural panels having metal on both faces and with the edges sealed, it also is very important that the moisture content of the wood core be kept low, especially if the adhesive film does not form an impervious water barrier between the two adherends.

In a previous paragraph, mention was made of the flatness of the final panel. This is an important consideration for most applications, and it becomes especially significant when the areas represented are comparatively large. With hot pressing techniques, it is essential that the cooling process be such as to cool both surfaces uniformly. If this is not done, the stresses will cause warpage. It is also equally important to have uniform conditions during the heating cycle. The trial and error method for each adhesive is perhaps the most practical solution. This problem is much less significant in cold gluing because there are no stresses due to differences in coefficients of expansion. In the matter of making a product having an unbalanced construction, such as metal or plastic on one face of plywood, the maintainance of flatness is very difficult, if not impossible. First of all, it can be said that to make such a product by the hot press method and expect it to be and remain reasonably flat is more of a wish than a reality. In cold pressing, the possibility is much greater especially as far as initial flatness is concerned. It is not possible to retain flatness because the construction is unbalanced; and, with the changes in humidity conditions, the wood will expand and contract resulting in stresses which manifest themselves in warpage. When making a product of this nature, a good rule of thumb to follow is to bring the plywood down to such a moisture content prior to bonding that whatever is added in the bonding operation the resultant average moisture content for the wood will be the same as is to be expected in service. Even then, changes in exposure conditions will produce stresses which may cause the panel to warp.

Since the several types of adhesives involve techniques which are distinct, we will discuss the techniques and type of adhesive simultaneously and consider them on the basis of the two general gluing methods mentioned above.

I. Cold Press

A. Rubber Adhesives: This includes a very large number of cements or adhesives having natural or synthetic rubber as the base, generally in an organic base solvent. The techniques employed in bonding vary with the adhesive and with the ultimate quality and type of product.

Perhaps the most common procedure is to apply the adhesive to either or preferably both of the two surfaces to be adhered. The glue is applied by brush, spray or roller coater. It is allowed to air dry for a specified time and then the surfaces are placed in contact with each other. Pressures ranging from essentially zero to a few hundred p.s.i. are applied to the assembly for a fraction of a minute up to several minutes.

There are many variations to the above general procedure. One of these which has been used successfully for several years incorporates these principles in bonding a metallic sheet to a composition board, such as masonite. The solvent is evaporated by passing the sheet through an oven of infrared lights. This also "activates" the adhesive because at the elevated temperature it becomes less viscous being thermoplastic in nature. The metal sheet is then laid on the adhesive surface and the assembly passed through a set of pressure rolls to effect the bond. This type of operation is economically practicable for volume production on a product which can tolerate a rubber type cement.

There are several possible methods for applying the adhesive to the surface. For very limited production, it may be practicable to deposit the adhesive film by brushing. Spraying is another common method. This, however, usually requires specially developed nozzles and guns and techniques peculiar to each adhesive. The deposited film tends to be spotty and globby. Many of these adhesives are also applied satisfactorily with a flow gun or by knife coating. The most prevalent method is by means of a roll coater which permits good control of quantity of adhesive applied and is economically practicable providing the production run is not too small.

A rubber adhesive film develops its strength due to the loss of solvent. The solvent is present primarily to give a satisfactory consistency for application and to wet the surfaces of the materials to be bonded. The more common bonding techniques are: (12, 15)

(1) Wet Bonds: The adhesive is applied to the least porous surface and the other surface is brought into contact at once. This bond may be satisfactory where exceptionally high strengths and resistance to cold flow are not required.

(2) Tacky Bonds: The adhesive is applied to one or both surfaces and allowed to air dry until an aggressive tack is developed. The time for this is dependent upon several factors, including temperature, humidity, air circulation. The surfaces are brought together during this tacky stage. Pressure is applied to assure intimate contact. Time under pressure may be momentary to several minutes.

(3) Reactivated Bonds: This technique is usually more applicable when

bonding together two surfaces which are impervious to passage of solvent or when it is not practicable to dry both surfaces to the optimum stage at the same time. High pressure plastic laminates are often bonded to plywood by this method. The adhesive is applied to the surfaces, allowed to air dry for an indeterminate time, even up to several weeks, and is reactivated by wiping the surfaces with the proper solvent and making contact immediately.

(4) Pressure-Sensitive Bonds: There are available rubber adhesives which, when dry, are tack-free to the touch or in contact with other materials. However, when two coated surfaces are brought together under comparatively low pressure, a bond is established.

(5) Chemically Cured Bonds: A two part adhesive is used. One is a catalyst or "accelerator" which, when mixed with the other, initiates a cure of the mixture. Because the curing begins at once, the time limit of the pot life of the adhesive mixture is short. After applying the adhesive to both surfaces by brush or roll coater, the assembly is made at once and put under pressure for several hours depending upon temperature.

(6) Combination Bonds: Another production method being employed successfully in bonding metal to wood incorporates the use of two rubber type adhesives. This apparently takes advantage of the fact that adhesives differ in polarity (see above), and the specific adhesion to the adherent is determined by these forces. An organic solvent type rubber base adhesive is applied as a prime coat to the metal. This is forced or air dried. The primary adhesive, a water-dispersed rubber base material, is applied to this primed surface of the metal and to the wood surface. These components are then air dried or passed under a bank of infra-red lights for three minutes at a temperature of 150° F. The assembly is then laid up and held under pressure for about three minutes.

B. Protein-latex: This type of adhesive (11) has been used in the commercial production of metal-faced plywood panels for at least twenty-five years. The protein (casein, blood albumin) has no great degree of specific adhesion for metals. Water-dispersed rubber lattices (natural and synthetic) are much better in this respect. A proper combination of the rubber latex and protein develop good bond strengths. With the proper formulation of ingredients and proper surface preparation of the metal or plastic and wood, the bonding techniques are comparatively simple. The adhesive is applied by brush, roll coater or spray to either of the two surfaces, and the assembly is held under clamp pressure for eight to sixteen hours. This adhesive "sets" principally through the loss of water. Having once lost the water through dissipation into the wood, the adhesive loses its property of being soluble or miscible in water and becomes highly water resistant.

C. Combination Primer and Cold Setting Glue: There are commercially available adhesive materials which have a very good degree of adhesion to metals. These are applied to the metal surface by conventional methods. The usual procedure is to air dry and follow with a bake or cure for several minutes at elevated temperatures. It is desirable that the surface of this primer lack a high degree of smoothness. This can be accomplished by method of application or else by roughening it after baking with a coarse sandpaper. The bond between the prime coat and the wood surface is made with a cold-setting resin adhesive such as urea, phenol, resorcinol type by using regular wood-bonding techniques. (6, 7)

D. Synthetic Resins: Within the past few years there have been developed a number of resins which are being used to an ever increasing extent in bonding metal to metal and metal to wood. This class of resins are known as the epoxies. There are several variations available depending upon the working, physical, chemical and quality and economic characteristics desired. In general, these resins are very expensive, costing at the present time as much as $2.00 or more per pound. The primary usage is for metal to metal bonding where little or no external pressure can be applied. This type of resin cures very rapidly when the proper catalyst is added. The chemical reaction which takes place is highly exothermic and thus the pot life of the mixture is very limited.

Certain formulations of this type of adhesive are considered as 100% solids. This means that they set without evolution of volatile by-products. Generally also the setting is accomplished with no material shrinkage. These characteristics make the resin not only suitable for bonding metal or plastic to wood, but also for bonding together impervious materials, such as metals, ceramics, rubber and glass.

The use of the so-called craze-resistant type of urea resins has been very successful in bonding decorative plastic laminates to plywood for table tops and similar applications. Also, the resorcinol, resorcinolphenol, cold-setting phenolic, and casein glues are being used successfully. The surface of the laminate is first roughened by sanding. The water solution of the resin is applied by customary means to the wood and the assembly is cold-pressed. It is possible to get satisfactory bonds at comparatively low pressures. Especially where fir plywood is used, this low pressure feature is very desirable because it prevents the hard and soft spots from telegraphing through to the glossy surface of the decorative laminate.

II. Hot Press

A. Resin-rubber: This type of adhesive, comprising a combination of synthetic resins and synthetic rubber, has become very common during the past decade. During World War II the aircraft industry, in particular, was in need of adhesives for bonding metal to metal to replace the time-consuming riveting procedures. Many formulations have been developed in the intervening years. Not only have these adhesives proven satisfactory for metal to metal bonding, but they also are used for metal to wood bonding where high strengths and very good durabilities are required. A straight resin adhesive is very strong and rigid, it tends to be brittle and often exhibits poor adhesion to non-porous surfaces, while a rubber adhesive is flexible and may have too much elasticity although it has good adhesiveness to metal. The proper combination results in exhibiting the merits of both without either of their disadvantages.

There are several liquid type adhesives of this general composition. The working properties of the uncured composition, as well as the physical properties of the final glue bond, are dependent upon the particular composition.

The general technique in using a typical formulation can be given as follows: The adhesive having a low solids concentration in an organic solvent is applied to each of the surfaces to be bonded by brush, spray or roll coater. In order to build up a sufficient film thickness, several applications with air or force drying between each may be required. A further drying or precure so as to remove all solvents is recommended. This may require 15 to 30 minutes at a temperature below the boiling point of water. The assembly is then subjected to temperatures between 300 and 400 degrees with pressures up to several hundred pounds per square inch depending upon compression resistance of the components being bonded.

In the aircraft industry, it is usually not possible or practicable to make secondary glue joints between metal and wood. Common procedure is to bond a thin wood veneer to sheet aluminum or stainless steel with a rubber-resin adhesive. (2) This veneer surface then can be bonded with a cold-setting resorcinol resin to the other wood part.

B. **Thermosetting - Thermoplastic Resin Combinations:** There are combinations of resins which have given very good metal to metal and metal to wood bonds. The one component is a synthetic resin of the phenolic type which cures (becomes insoluble and rigid) when subjected to heat. The second component, also a synthetic resin which may be of the formal or butyral type, remains plastic even when heated for long periods at elevated temperature. The mixture, however, when properly cured, exhibits the general properties of a thermosetting resin. (7)

"Redux"[b] is an adhesive of this type. It has been in use in England and this country for over ten years especially for making high strength bonds between metal parts in the aircraft industry. (5, 9) The process requires extreme care in proper cleaning of the metal surface. The one component, in liquid form, is applied to the surfaces; and before it has dried, the second component, in powder form, is sifted on the wet surface of the metal. The excess powder which does not cling to the liquid should be tapped off. After an open assembly time of at least 30 minutes (most common is from a few hours up to two days), the assembly is made and put into a hydraulic press with platen temperature at about 300° F. The curing time is comparatively long—about 30 minutes.

The general type of adhesive is also available in the liquid form—the mixture of resins being dissolved in organic solvents. The viscosity is usually rather high in comparison with the solids content, in this respect being much like lacquer. One proprietary resin of this type at about 20% solids has a viscosity in the general range of 20 to 30 seconds in an ASTM No. 25 cup at 25° C. Either surface is coated with the adhesive, the solvents are removed by normal air or force drying, and the assembly is subjected to a pressure of 25 to 200 lbs. per sq. in. for several minutes at temperatures between 300 and 350° F.

For bonding small parts or components which do not lend themselves readily to coating with the liquid resin, this type is also available in the film form. It is supplied as a tack-free unsupported film[c] approximately two mils thick. There are also available commercial sheets on glass fabric base with varying amounts of resin coating.[d]

Bonds made with this type of adhesive have considerable resistance to water, alcohol, organic solvents, oil, etc. They also have exceptionally high shear strength and resistance to creep under sustained loads. This latter property, however, holds only at temperatures below 200 to 250° F. At higher temperatures, the bond tends to show thermoplastic characteristics.

C. **Synthetic Resins:** The epoxies (3) or ethoxylene resins are cured at elevated temperatures as well as at room temperature. Several formulations of this type of resin have a high degree of specific adhesion for most non-porous surfaces and readily wet the surface. It is thus possible to get good bonds without requiring high pressures.

The resin, supplied in a liquid condition, has a reasonably good storage life at room temperature although it is best to store in a cool place. It can be applied by brush or spray. Precautions are necessary because the solvents are inflammable. Although not essential, it is best to air dry the open assembly at a temperature below 120° F. After drying, the components can be assembled and cured at once; or the curing process can be delayed up to several months. The resin melts at a temperature of about 250° F. so in order to get a bond having high shear strengths and good resistance to solvents, the curing temperature should be above the melting point. The time required to cure the resin depends upon the temperature. One-half hour at 400° F. gives very good results. At 300° F. the time is increased to about 4 hours.

The disadvantage of long curing time at high temperatures for this type of resin is offset by the fact that only good contact pressures are required. Therefore, the curing can be done with clamp pressures in ovens without requiring hydraulic presses with heated platens. Because of the comparatively high cost of the resin, the use thus far has been in bonding small parts rather than in commercial applications involving products having large areas.

Conclusion

The foregoing covers only a small part of the many factors involved in bonding metal and plastics to wood. By listing several of the types of adhesives available, as well as their general working properties and other physical characteristics, it is hoped that this will serve as a preliminary guide in the selection of a specific adhesive for a particular job.

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(5) ——: Metal to Metal and Metal to Wood Gluing; Sept. 1946, Resinous Products and Chemical Co.

(Continued on page 218)

[b] Trade-mark of Ciba Company, Inc.

[c] Minnesota Mining & Manufacturing Co.

[d] Bloomingdale Rubber Company.

Properties and Application of Amino Resin Adhesives and Binders

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This paper gives a short history of the development of synthetic adhesives followed by a description of amino resins, principal raw materials used in their manufacture, and mention of their principal applications. The development and uses of four modified urea resin adhesive binders are described in some detail. The four resins are: (1) urea-formaldehyde resins with improved water resistance, (2) gap-filling urea adhesives, (3) fast clamping cold set adhesives, and (4) wet strength resins. Melamine resins are touched upon for their use as wet strength resins and in the manufacture of decorative laminates. A few paragraphs on the future uses for amino resin binders concludes the paper.

DURING THE LAST forty years synthetic resin adhesives have grown from their inception as an idea in the mind of Baekeland in 1912 to their use in the bonding of motors to airplanes in recent years. The volume growth from practically nothing in 1912 to several hundred million pounds in 1952 is even more striking when it is realized that most of this growth occurred since 1930 when the first of the amino resin adhesives, urea-formaldehyde resins, were offered commercially.

This period of growth saw many new synthetics invade the adhesives field. In the 1920's, exploitation of cellulose esters, rubber, cyclized rubber, and chloroprene was begun. These were largely used as solutions in organic solvents. Then the urea-formaldehyde resin adhesives made their appearance, followed by polyvinyl butyral, polyvinyl acetate, chlorinated rubber, melamine-formaldehyde resins, and resorcinol-formaldehyde resins. More recently, the latex adhesives, the ethoxylene type adhesives, and the polyurethanes have made their appearance. Who would dare guess what products will be added during the next decade?

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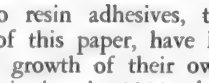
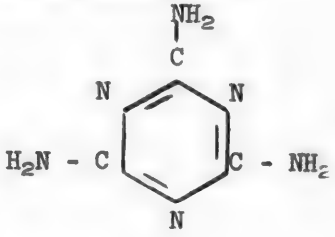
Amino resin adhesives, the main subject of this paper, have had phenomenal growth of their own. Since their beginning in 1930, the annual volume of amino resins sold for use in binders of various types reached 80,000,000 lbs. (solids basis) in 1951. Considering the many properties of these resins that render them ideally suited to many adhesive applications, this is no surprise.

The term "amino resin" may be confusing to the layman since chemists, who are so exact in their work often adopt descriptive names that appear to have no precise meaning; "amino resin" belongs in this category. (An amino resin usually denotes a resin that has been derived from an amino compound; an amino compound being one that contains an amino group; and an amino group is the chemical group H_2N–.) Compounds containing such groups are very common. The proteins that form the building blocks of our bodies and which taste so good when in the form of charcoal broiled steaks are compounds of this type. For the purpose of this paper, it will suffice to mention only two amino compounds that are used to make amino resin adhesives, for these two account for more than 95% of the total amino resin commercial products. The first is urea. The chemist pictures this compound as follows:



Urea

The second compound is melamine; again the chemist's picture:



Melamine

The amino groups (H_2N–) of both these materials react with formaldehyde under suitable conditions to form large complex molecules. The first products are not so complex (although chemists are still debating their actual structure) and they are water soluble. In this form, they can be used as binders, but if the final bond is to be water resistant, the resin must be made more complex. This can be done by continuing the reaction at the time the adhesive is used. Thus, a cold set urea adhesive is reacting, because of the catalyst it contains, while it is in the glue pot and after it is in the glue line. This reaction continues until the resin molecule becomes so large it can react no further. It is then insoluble and infusible. A similar reaction takes place when an urea resin or a melamine resin is cured with heat. This is an over-simplified and not entirely accurate explanation, but since it is not the purpose of this paper to become bogged down in the numerous theories of resin structure, it should suffice.

Usually, there is some interest in the source of the chemicals that go to make up any product. In the case of amino resins, where only three main chemicals, urea, melamine, and formaldehyde are involved, it is possible to say with all honesty that they are made from coal, air, and water. They are, therefore, assuming ample plant capacity, available in unlimited quantities at moderate cost. Urea and for-

Table 1

Property	Urea Adhesives	Melamine Adhesives
Physical Form	Dry powder or syrup	Dry powder or syrup
Solvent	Water	Water
Storage Stability	Excellent	Excellent
Extendability	Excellent	Limited
Working Life	Hours—cold set Days—hot set	Days—hot set
Spreading Characteristics	Excellent	Excellent
Type of Catalyst	Acid	None
Curing Temperature	Room Temp. to 250°F.	190–250°F.
Curing Time	Very short—hot set 4–8 hrs. clamp plus several days to max. strength—cold set.	Short—hot set
Type of Bond	Thermoset	Thermoset
Color of Bond	Colorless	Colorless
Bleed Through	Nil	Nil
Bond Durability	Excellent Indoors Not recommended outdoors although protected joints may be satisfactory.	Excellent
Cost	Very low	Moderate

maldehyde are manufactured at an annual rate of more than one billion pounds per year and the melamine volume is over 100 million pounds per year.

In order to compare the two major amino resin adhesives, the properties of the urea-formaldehyde and the melamine-formaldehyde adhesives are listed in Table I. These properties are for the unmodified adhesives that have been specifically formulated for use in plywood.

A little study of the table shows that urea adhesives have three main advantages: (1) low cost, (2) ready extension with wheat flour, and (3) cold setting properties. The melamine adhesive on the other hand has the excellent durability required for exterior use. The lack of bleed-through and the colorless glue line of both adhesives make them ideally suited to the gluing of hardwood plywood, while fast cure at moderate temperatures assures a low cost streamlined operation.

Unmodified urea binders, consisting essentially of water and urea-formaldehyde resin with or without extenders, are well known throughout the industry. Many are also familiar with their principal uses: interior plywood, lumber core, woodwaste boards, flush doors, paperboard, etc. Since these applications have been the subjects of many papers, further discussion here is not deemed necessary.

There are a number of modified urea resins that are important but not so well known and therefore deserve further attention. Four items will be described: (1) urea resin adhesives modified for better water resistance, (2) urea resin adhesives modified to give gap-filling properties, (3) urea resin adhesives modified for faster clamping properties, and (4) urea resins modified to impart wet strength to paper. In each case, a brief study of the development of the resin will be given, followed by an account of the main applications for the material.

Urea resin adhesives were hardly born before the chemist was attempting to improve their water resistance. Phenol resins were some of the first materials used for this purpose and there are several literature and patent references relating to this combination. However, alkaline cure, which is best for phenolic adhesives retards the cure of urea resins and the high temperature cure of the phenolic is harmful to the urea resin. Furthermore, the colorless glue line of the urea adhesive becomes highly colored when modified with phenol. Phenolic modification did not appear to be the way to improve the water resistance of urea adhesives. Recently, there have been attempts to realize improved water resistance in urea resin adhesives by modifying with resorcinol. This development cannot be evaluated until more experience with this system has been obtained, although it is possible to predict that color and cost will not be favorable.

While one group of chemists attempted to improve the water resistance of urea adhesives through phenolic modification, a second group was having more success by modifying with melamine. Here, the chemical species were similar so no trouble in either cure pH or cure temperature was encountered. First melamine crystal, then melamine resin was mixed with the urea resin; in both cases improved water resistance was obtained. However, it was only when the urea and melamine resins were coreacted that optimum water resistance was obtained. For instance, in a controlled series of experiments, it was found that the coreacted adhesive met the exterior plywood shear strength requirements after two cycles of Type I CS–35–49, and partial delamination occurred only after eight cycles. The blended adhesive, on the other hand, failed to meet the exterior plywood requirements after one cycle. This improvement in water resistance is reflected in both simulated and actual outdoor durability tests that have been run. To date, improvement in water and weather resistance is shown only in hot set adhesives. If a similar modification of the cold set urea has been worked out, it has not yet been announced publicly.

Unmodified urea resin adhesives produce excellent bonds when the glue line is thin, i.e., up to about 0.007 inch thick. Glue line thickness can be maintained in this rather narrow range through the use of pressure on veneer, or by precisely finished lumber parts. Prior to World War II, chemists had realized the advantages that would accrue from the development of an adhesive that would bond well even if the glue line was as thick as 0.020 inch. During the war such an adhesive was used by the English in the manufacture of their famous all-wood Mosquito bomber. A vivid account of this work was given by Mr. C. H. Pottenger at an earlier meeting of this society (3). No purpose would be served by reviewing that report, but some previously unpublished development work on the first American gap-filling adhesive (1) should be of interest.

The English adhesive that functioned so well in the Mosquito, was a urea-formaldehyde resin modified with benzyl alcohol. The purpose of the benzyl alcohol was to act as a completely compatible solvent which replaced much of the water used in the conventional urea adhesives. Having a high boiling point (401° F.), this solvent, unlike water, remains in the cured adhesive, thus reducing shrinkage and consequent crazing.

In 1943, there seemed to be a large American market for a cold-setting gap-filling adhesive, but the English product had several disadvantages when considered for the American market. The limited shelf-stability and the low glue line pH (below 2.5) were sales handicaps, but the poor durability of the cured bond under the extreme temperature and humidity conditions of the United States made this formulation only slightly better for use in this country than unmodified urea-formaldehyde adhesives. This latter objection did not apply when the adhesive was used in England where the humidity and temperature varied but little. Although the Mosquito bomber was used in every clime, no glue failure was ever proved; showing that there is a tendency here in America to be overly cautious in the interpretation of durability test results. However, in 1943, with this experience yet to be gained, it seemed necessary to correct these disadvantages by changing the English formulation or by developing a new one.

After an exploratory look at a number of possible modifiers, and after trying unsuccessfully to correct the disadvantages of the English formulation, a detailed study of urea-formaldehyde resins modified with furfuryl alcohol or furfural was programmed.

With either of these systems, it was reasoned, the modifier would polymerize at the same time the urea resin cured under the influence of an acid catalyst. The compatible modifier would then be in the form of a high polymer well distributed throughout the cured urea resin. Being a high polymer and having practically no vapor pressure, the modifier would have no tendency to be lost even at elevated temperatures; shrinkage should be low and crazing should be minimized if not completely eliminated. This is just how it turned out. Furfuryl alcohol was preferred to furfural because it had better compatibility with urea resin and because it was more easily polymerized in the presence of dilute acids.

Uses for the gap-filling urea adhesive have increased steadily since their commercial introduction in 1945. Today, of the many applications for this adhesive, four main ones stand out: (1) for bonding decorative laminates to plywood; (2) for bonding hardboards, such as Masonite, particularly in the construction of hollow core doors; (3) for general assembly work such as the bonding of butcher blocks; and (4) for home repairs. Each of these main applications illustrates one or more properties of this adhesive that are valuable and unique. In bonding decorative laminates, the low pressure that can be used not only permits varied application techniques but it also eliminates grain register through the decorative laminate. In the manufacture of hollow-core doors, low pressure is advantageous and the reinforcing action that is obtained by having a craze-resistant bond of adhesive pile up at the union of the core and face is very desirable. Furthermore, extremely good Masonite bonds are obtained with this adhesive. In assembly work the advantage of less precise fitting is obvious; a more subtle advantage is the heat resistance which permits the use of baking finishes without bond deterioration. For home repairs, these adhesives are almost ideal. They can be used under a wide variety of conditions without careful attention to proportions of ingredients and without intricate pressure systems. In short, Mr. Handyman finds he can be handier if he has some craze resistant urea adhesive at hand. The relatively new gap-filling urea adhesives are well established in the industry. Their continued growth seems certain.

During the last ten years the trend in plywood manufacture has been away from cold setting operations and toward hot setting ones. This is readily understood when the long clamp time at room temperature is compared with the short cycle in the hot press. However, with clamping time shortened to a few minutes, cold setting processes would again be attractive. With this in mind, the chemist began working toward fast clamp adhesives.

There are a number of products on the market today that have very fast clamping times. Most of these are thermoplastic emulsions formulated so they have an affinity for wood and so the emulsion breaks when it comes in contact with and loses water to the wood it is to bond. These particular products have two disadvantages: (1) water resistance is only fair, and (2) being thermoplastic, the bonds fail at somewhat elevated temperatures. Work on the elimination of these disadvantages is underway in a number of laboratories; there follows an account of one study along these lines.

Emulsion adhesives consist of about 50% water and 50% special polymer. So much water in the system suggests that water soluble resins might be used to increase both water resistance and heat resistance of the adhesive. Since cold setting properties would be not only desirable but necessary, the use of urea-formaldehyde resins was a logical selection for the initial trials.

At first, mixtures of the emulsion and water solutions of urea-formaldehyde resins were studied. Improvements in water resistance and heat resistance were obtained at once. Clamp time, however, was lengthened. Continued investigation indicated it would be more logical, particularly from the economic standpoint, to modify the urea resins with latex. Clamping time now was improved over the urea-formaldehyde adhesive but still was not nearly as short as desired. Further improvement was obtained by spray drying the combined resins. By this approach it was eventually possible to produce a dry resin that could be re-emulsified and handled much the same as a conventional urea adhesive (2). In the laboratory, under ideal conditions, clamp times of only 10 minutes have been obtained with this formulation. In the field, a minimum clamp time of 20 minutes is the best that has been obtained to date.

The following shear strengths for gum plywood and maple blocks are typical of results obtained to date with this adhesive.

3/20" Gum Panels
Clamping Time—20 Minutes

	P.S.I.	% W.F.
Dry Shear	353	100
Wet (48-hr. soak)	396	86
CS-35-47 (3 hrs. soak at 145°C.)	421	82
CS-35-49 (Type II)	25 cycles	

Maple Block Shear
(Federal Specification C-G-496)

15-minute clamp	2450	80%
30-minute clamp	3200	90%

The uses for fast clamping adhesives are obvious. Those who are now using cold set adhesives would welcome such a product. In the manufacture of hollow core doors where cold setting is often mandatory, this product would be ideal. In lumber core gluing and in assembly work a high quality fast clamp urea adhesive would find a ready market.

Another interesting modification of urea resins is in the field of wet strength resins for paper. In this application the wet strength of the paper is increased from 20 to 50% of the dry strength by treating the paper pulp with 1% to 5% of resin. When it is realized that only 1% or less pulp is in the feed to the paper machine, it is recognized that the retention of the small amounts (0.05% or less) of resin may be a problem. Retention of the resin by the pulp depends mainly on the following factors: molecular size of the resin, constitution and ionic character of the resin, presence of electrolyte, and nature of the pulp. Optimum characteristics are best obtained by modification of the urea resin. The two most common modifications can be broadly classified as anionic and cationic.

The most common anionic urea resin is sodium bisulfite modified. Urea, formaldehyde, and sodium bisulfite are reacted together first under alkaline conditions, then under acidic conditions. The resulting water soluble viscous resin is commonly used in conjunction with a precipitating agent, such as alum. After the paper is formed, resin cure takes place while the paper is drying, and continues for some time thereafter.

The positive charge on the cationic urea wet strength paper resins, is acquired through the presence in the resin molecule of a basic nitrogen group in combination with an acid. A large number of compounds can be used to modify the urea resin in this way; one of the most common is triethylene-tetramine. The resin reaction in this case is similar to that described for the anionic type, and so is the resin cure. However, in this case, no precipitating agent is needed since the paper pulp, being negatively charged, has an ionic attraction for the cationic resin.

With either type of resin, the imparted wet strength depends on the quantity of resin retained on the pulp. Of the several factors that influence retention, molecular size is one of the most important. In studies where the effect of resin molecular size on the quantity of resin retained in the paper was determined, it was found that regardless of resin type, the retention (and wet strength) increases as the

molecular size of the resin increases up to a point beyond which further increases in molecular size cause no further increase in retention. In the formulation of such resins, it is therefore important to end up with a resin molecule that is large enough to give optimum retention and wet strength.

Melamine resins are also used as wet strength paper resins. Here, too, the resin is most effective when it has some ionic character. Cationic melamine resins are commercially used to the practical exclusion of other types. They are made by forming a hydrochloric acid colloid by merely aging the melamine-formaldehyde resin in a dilute solution of hydrochloric acid (4). Retention of this resin is affected by the same factors that affect the urea resins.

Further information about wet strength resins and about other water soluble amino resins can be found in the article titled "Resins as Finishing Agents" by D. G. Patterson, et al, in the March 1952 issue of Modern Plastics.

Melamine resins have been found to be ideally suited to the manufacture of decorative laminates. Here the excellent color and color stability of the melamine resins combine with high heat resistance, extreme hardness, and scratch resistance to form an article of great beauty and wide utility. Products of this type are used very successfully for bar tops, counter tops, table tops, and the wearing surfaces of many other articles.

Melamine resins for laminating use are generally of a 1:2 to 1:3 melamine/formaldehyde ratio and are either spray dried or kettle dried and shipped as powders. Liquid resins have also been used but the powders are preferred because of better storage stability.

The typical decorative laminate structure is quite simple. Several sheets of phenolic resin impregnated Kraft paper forms the core of the laminate, acting as the main body of the sheet and also serving as a hard dent-proof backing for the decorative surface. Decoration is obtained by printing on a highly pigmented, high quality alpha paper. This print sheet is impregnated with melamine resin, as is the uppermost sheet, which is called the overlay. The overlay is 3–5 mils thick, it contains a high percentage of resin, and it is made as transparent as possible. It protects the print sheet from wear.

All the papers are impregnated in the usual way using water or water-alcohol solutions of melamine resin. They are usually dried in vertical infrared or hot air ovens. The quantity of resin used in the core is 30–35%, the print sheet 45–50%, and as much as 70% in the overlay. The dried papers are assembled in the proper order, placed between polished cauls, and pressed for 15–30 minutes at 135–150° C. and 1000–1200 p.s.i. Common practice is to charge cold and cool before opening the press. When discharged, the laminates need only be trimmed before they are ready to be glued to plywood or other backings used in table tops or wall surfaces.

The principal uses for amino resin binders in forest products have been reviewed. There has been no attempt to make this a complete catalog of either amino resin or applications for amino resins. However, no effort of this kind is finished until some prognostications, either dire or wonderful, are made. This is a fitting custom, for when, if not on an occasion like this, could the chemist step out of character long enough to be a fortune teller? Of course, it must be understood, just as it is with "Gypsy Joe", there are no guarantees.

No crystal ball is needed to predict a great future for the hardboard, the chipboard, the sawdust board, or whatever name is preferred. Regardless of title, this board is certain to play a more and more important role in the economy of the country. The ever-increasing shortage of fine veneers and full grown trees emphasizes the logic behind this prediction. While they are already used in large volume in this growing field, amino resins with their good water resistance, excellent color, fast cure, and reasonable price, will be used in still greater quantities.

Next, and closely related to the hardboard, is the upgraded board. This includes the low grade plywood, the hardboard, the woodwaste board, etc. that has been covered with resin impregnated paper, plastic film, or some other surface. One can visualize such surfaces all the way from a single sheet of urea resin impregnated Kraft paper to an assembly of two or three sheets of finest alpha paper impregnated with melamine resins. Truly, the amino resins have a great future here.

The third vision is akin to the first two. As the great American forests become depleted and Americans are forced to rely almost entirely on the farmed forest of small trees, sandwich cored materials with paperboard centers and hardboard, veneer, or plastic laminate surfaces will find ever-increasing uses. Again, amino resin binders and impregnants will find an expanding market.

There seems to be a great future for laminates of dissimilar materials. For instance, clapboards made of hardboard surfaced with very thin stainless steel would be light, strong, and everlasting. Sheathing coated with aluminum would have greater strength and durability; it would insulate, and it would be a vapor barrier. Other dissimilar laminates have special strength properties; for instance, single veneers laid in the same direction and bonded to either side of a piece of glass cloth have unexpected strength. Before combinations of materials such as these are commonplace, new or improved low-cost adhesives will have to be developed. This is a challenge to the chemist; he is sure to meet it.

Foretelling the future is a fascinating game, since it usually entails so little responsibility and yet offers the chance a prediction will come true to justify the oracle's optimism. However, once started, there is danger this game might run on and on *ad infinitum;* so reluctantly, this phase of the paper is concluded.

This paper has described the several types of amino resin binders and adhesives. It has pointed out that the good color, the fast cure, the durable bonds, and the versatility of these products assure their future growth. The newer modifications of the urea resins, the gap-filling adhesive, the melamine modified resin for exterior use, the fast clamping cold set glue, and the wet strength paper resins are only in their infancy. This is also true of the melamine resins. Future resin developments in this field will undoubtedly add to the list of growing products. In the new applications that have been forecast, amino resins will also play a major role. Surely the future of amino resins will be influenced by the future of forest products, and vice versa.

References

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2. American Cyanamid Co., U.S.P. 2,592,510.
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Discussion

M. M. Selbo: Are high temperature cures harmful for urea resins?

Detwiler: Yes 300°F is too high—there is a tendency to overcure.

M. M. Selbo: Are acid cures harmful?

Detwiler: Very acidic phenolics seem to attack the wood cellulose thus resulting in poor bonds. Ureas are not usually used with such strong acids.

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Durability of Woodworking Glues in Different Types of Assembly Joints[1]

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Seven types of assembly joints commonly used in furniture were glued, each with 11 different glues representing 6 glue types. Representative groups of specimens were exposed to repeating cycles that caused the moisture content of the samples in the group to change from, approximately, 6 percent to 11 percent, 6 percent to 16 percent, and 6 percent to 20 percent, respectively. Specimens of each joint from each group were tested at intervals over a period of 36 months. Side-to-side grain joints were least affected by the moisture content changes, and the blocked joints were the most affected, with the loss in strength of the blocked joints being particularly marked in the more severe cycles. Under the most severe cycle, the resorcinol and the phenol-resorcinol glues were generally the most resistant to weakening. The polyvinyl-resin glue performed well in the dowel and in the slip or lock joints.

The data have been presented in detail to illustrate variations of test results between different types of joints and between different groups of samples of the same type of joint, as well as the general behavior under different conditions of exposure. The variations suggest caution in interpreting the exact reproducibility of results, especially the significance of differences among the glues in the different joints and exposures, but the general trends are believed to be reliable and of interest to furniture manufacturers and others producing similar assembly joints.

Introduction

STANDARD PLYWOOD shear test specimens (A.S.T.M. 906-409) have been widely used in studies of the durability of woodworking glues. Since the stresses in various types of furniture assembly joints may vary considerably from those that develop in plywood under changing moisture conditions, it was thought desirable to study the performance of glues in such commonly used joints as mortise-and-tenon joints, slip or lock joints, block joints, dowel joints, and edge joints, as well as in less commonly used joints such as end-grain-to-side-grain and 45° end-grain-to-side-grain joints.

The work was done in cooperation with the Research and Development Division of the Office of the Quartermaster General, Department of the Army. Since this agency must supply office equipment, furniture, field equipment, and other items to military bases in widely separated parts of the world, glue joints are needed that will be durable under wide variations in climatic conditions. For this reason rather wide variations in moisture conditions were chosen for the exposure tests in this study.

Procedures

The seven types of joints used in this study are shown in figure 1. The species was hard maple of clear and fairly straight-grained material. The side-grain-to-side-grain specimens were exposed in the form shown, figure 1, *G*, but were tested in compression-shear after cutting five shear block specimens from each joint. All other types of joints were prepared, exposed, and tested in the forms shown in figure 1. The formulas of the glues used are given in table 1. All of the wood members were at approximately 6 percent moisture content when glued. In general, the wood parts were machined shortly before gluing, using conventional woodworking equipment, with special care being taken to insure that all specimens of one type were machined as nearly as possible to the same tolerance. The dowels were commercially made with spiral grooves and, in addition, had two straight grooves running the length of the pin. The ends were chamfered to blunt points. The diameters of the dowels and of the holes (fig. 1, *A*) were measured, and dowels and blocks were paired to give a difference of 0.005 to 0.007 inch between hole and dowel diameters in each specimen. Generally, glue was applied to both joint surfaces by hand spreading and the joints were assembled immediately. Dowel and mortise-and-tenon specimens were forced together and held in a vise for approximately 1 minute before release for final curing without external pressure. The blocked joint (fig. 1, *C*) was assembled in a jig immediately after spreading, screwed together, and then removed from the jig. The other specimens (fig. 1, *E*, *F*, and *G*) were held under a pressure of approximately 125 pounds per

[1] This work was done in cooperation with the Research and Development Division, Office of the Quartermaster General, and was financed in part by that agency.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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ABOUT THE AUTHOR: OLSON, WARREN Z. Does research in the properties and characteristics of glues. Received BS degree from the University of Wisconsin. Author of several U. S. Forest Products Laboratory Publications.

square inch for 16 hours after assembly. All joints were assembled at normal room temperature (70° to 80° F.) and were then cured at a temperature of 80° F. and 30 percent relative humidity for at least 7 days before control tests were made. The screws were removed from the blocked joint (fig. 1, *C*) before testing.

Ten specimens of each type with each glue were selected randomly and tested before exposure to furnish an average control value (0 month of exposure, tables 2 to 7, inclusive). One group of specimens of each type of joint was exposed to each of the following conditions:

1. A repeating cycle consisting of 4 weeks in air at 65 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F. During this cycle the moisture content of the specimens would change from about 6 to 11 percent.
2. A repeating cycle consisting of 4 weeks in air at 80 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F. During this cycle the moisture content of the specimens would change from about 6 to 16 percent.
3. A repeating cycle consisting of 4 weeks in air at 90 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F. During this cycle the moisture

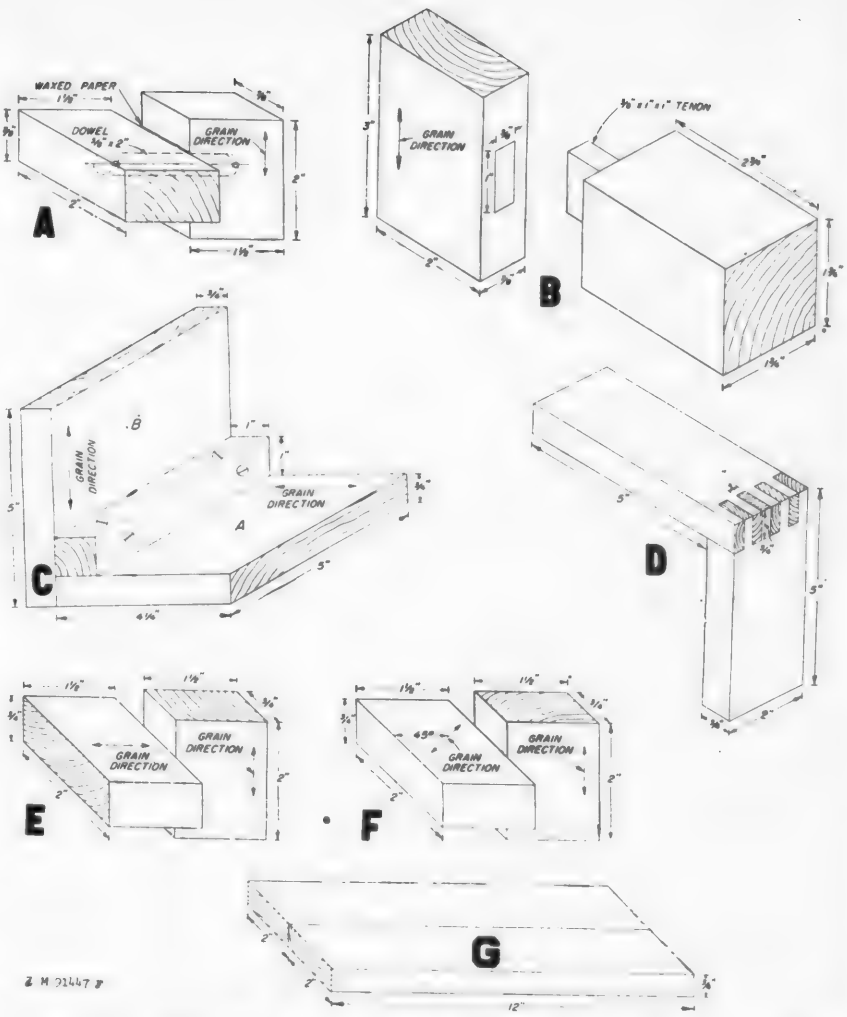

Figure 1.—Seven types of joints used in durability tests. A, dowel joint; B, mortise-and-tenon; C, blocked; D, slip (or lock); E, end-grain-to-side-grain; F, 45 degree end-grain-to-side-grain; and G, side-grain-to-side-grain.

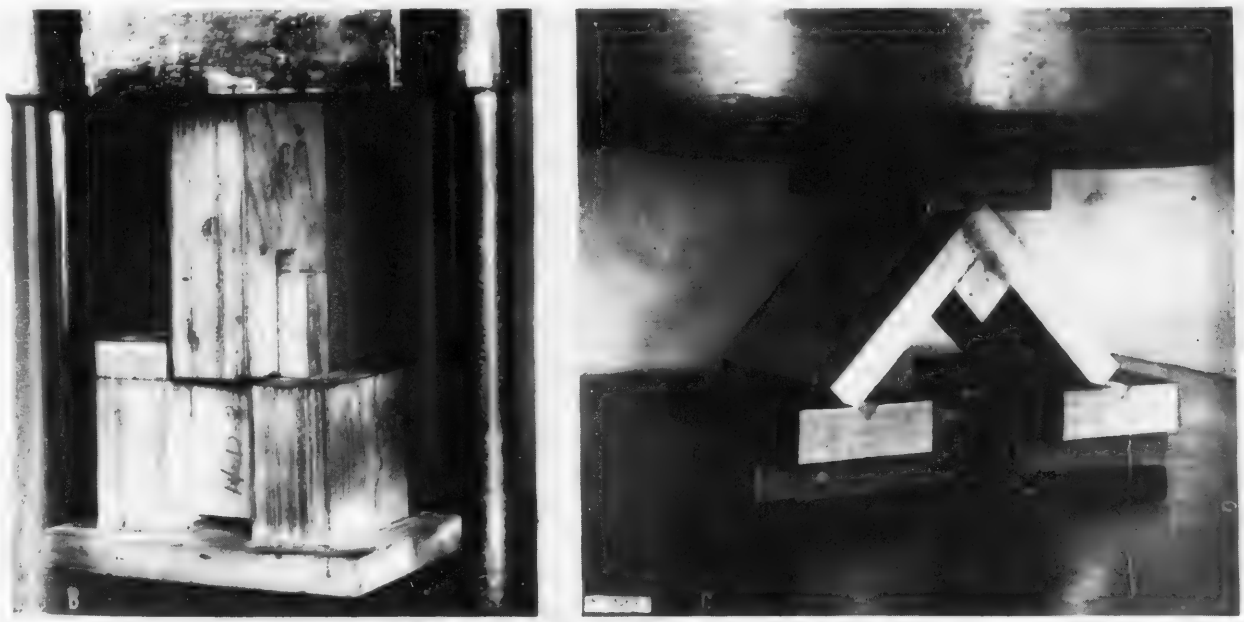

Figure 2.—Mortise-and-tenon joint (B) and block joint (C) in position for test.

content of the specimens would change from about 6 to 20 percent.

The 80–30 percent relative humidity exposure was added after an appreciable amount of data had been obtained from the two other exposures. The purpose of the additional exposure was to determine if glues that showed deterioration of joint strength in the 90–30 exposure would maintain their strength in the less severe exposure. For this reason glues that performed well in the more severe exposure were omitted from the milder 80–30 exposure. One type of joint, the 45° end-grain to side-grain, was also omitted because the results obtained with it in the earlier tests were somewhat similar to those obtained with the end-grain-to-side-grain joint.

Tests were made after 6, 12, 18, 24, and 36 months of exposure. Five specimens of each type of joint made with each glue and from each exposure condition were selected randomly and tested after each period. The testing was done at the end of the low-humidity part of the cycle. Dowel, mortise-and-tenon, end-to-side-grain, and 45° end-grain-to-side-grain specimens were tested by forcing them apart in suitable jigs so that the glue joints were in tension-shear or tension (fig. 2, *B*). The blocked joints and slip joints were tested in compression by loading at the corners with the two sides free to move apart on the bed of the test machine (fig. 2, *C*). All tests

Table 1—GLUE FORMULAS USED IN MAKING ASSEMBLY JOINT SPECIMENS

Glue designation	Basic glue type	Ingredients and amounts[1] used in glues: Resin or glue solids[2]	Water	Hardener	Preservative	Walnut-shell flour	Other
A1[3]	Animal	100	200	-----	-----	--	-----
A3[3]	Animal	100	168	-----	4[3]2.0	--	[5]
A4[3]	Animal	100	200	-----	[6] .5	--	[7]
B2	Casein	100	210	-----	[8] 5.0	--	-----
D2	Urea-resin	100	65	[9]1.00	-----	10	[10]1.20
D12	Urea-resin	100	---	12.00	-----	--	-----
D13	Urea-resin	100	55	[11]	-----	--	-----
F	Resorcinol-resin	100	---	25.00	-----	10	-----
G1	Phenol-resorcinol-resin	[12]100	---	20.00	-----	--	-----
I	Phenol-resin (acid-catalyzed)	100	---	12.00	-----	10	-----
J2	Polyvinyl-resin emulsion	[13]100	---	---	-----	--	-----

[1] In parts by weight.
[2] Includes solvent or vehicle when the glue (or resin) was received in liquid form.
[3] The animal glue used was J2 grade, in accordance with Federal Specifications.
[4] A proprietary preservative solution.
[5] A proprietary coagulant was applied to one of the mating surfaces.
[6] A preservative containing 6.25 percent ethyl mercury phosphate as the active ingredient.
[7] Aqueous 10 percent formaldehyde solution was applied as a coagulant to one of the mating surfaces.
[8] Sodium pentach orophenate.
[9] Ammonium chloride.
[10] Tricalcium phosphate as a buffer in the hardener.
[11] Hardener was incorporated in the resin.
[12] Resin solution, containing about 50 percent resin solids.
[13] A liquid glue, used as received.

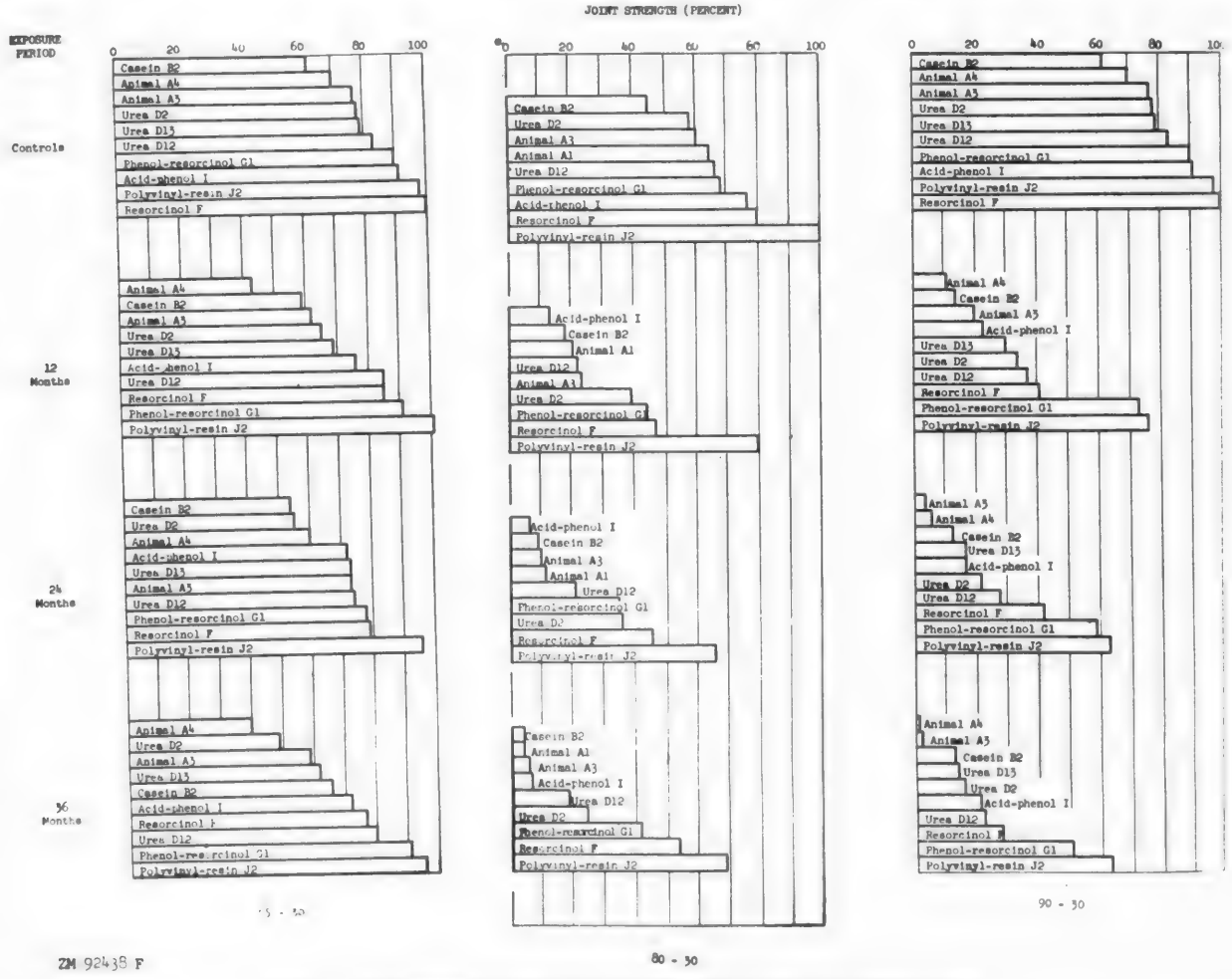

Figure 3.—Performance of various glues in dowel joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80° F.

were made in a hydraulic test machine with a rate of head movement of 0.025 inch per minute. The side-to-side-grain specimens (fig. 1, *G*) were cut into five separate block-shear-type specimens, each with a test area of ¾ by 1½ inches, after exposure, and these specimens were tested in a hydraulic test machine in the manner prescribed in ASTM Method D905-49.

For the sake of convenience in notation, cyclic tests Nos. 1, 2, and 3 will generally be referred to, respectively, as the 65–30, the 80–30, and the 90–30 exposures or cycles.

Results and Conclusions

The test results are given in tables 2 to 7, inclusive. Tables 3, 5, and 7 were prepared in order to facilitate evaluation of the test results. The highest average control test value developed by any one glue (in tables 2, 4, and 6) for each type of joint was chosen as the basis for comparison of all glues at each test period with this type of joint. All other test values for a particular type of joint were expressed as a percentage of this highest average control value. This method was selected because of the wide variation in control test values for the different glues in the same type of joint and because it provided a direct comparison of the performance of the different glues in the joint involved.

Bar graphs of the percentages given in tables 3, 5, and 7 are shown in figures 3 to 8, inclusive. In these figures the glues are arranged in order of increasing joint strength, expressed in percent of a common basis for each type of joint, to facilitate ready comparison of their performances. Since the performance of the 45° end-grain-to-side-grain joint was not widely different from that of the end-grain-to-side-grain joint, the results of only the latter are shown graphically.

The results for the different types of joints are discussed in the following paragraphs.

Dowel Joints: In the dowel joints (fig. 3) the polyvinyl-resin emulsion glue retained the highest percentages of the control strength after 36 months in all three exposures. The retained strength was nearly 100 percent in the 65–30 percent relative humidity cycle, and about two-thirds of the control strength in the 80–30 and 90–30 percent relative humidity cycles. The phenol-resorcinol-resin glue was next in strength retention in the most severe and in the mildest cycle, but was third (after the polyvinyl-resin and resorcinol-resin glues) in the 80–30 percent relative humidity cycle. The order of decreasing strength retention (including all glues used) in the 90–30 cycle was as follows: polyvinyl-resin, phenol-resorcinol, resorcinol, noncrazing urea-resin (D12), acid-catalyzed phenol-resin, urea-resin, casein, and animal. (Both modifications of animal glue contained preservative and coagulant.)

The average strength retained in the dowel joint after 3 years in the 90–30 percent relative humidity exposure varied from a low of 1 percent of the control with the animal glue A4 to a high of 63 percent with the polyvinyl emulsion glue J2.

Mortise-tenon Joints: In the mortise-and-tenon joints (fig. 4) the phenol-resorcinol and the resorcinol glues were among the three top performers after 36 months in all three exposures. The noncrazing urea (D12) retained the highest strength in both of the two milder exposures, and the acid-catalyzed phenol and the phenol-

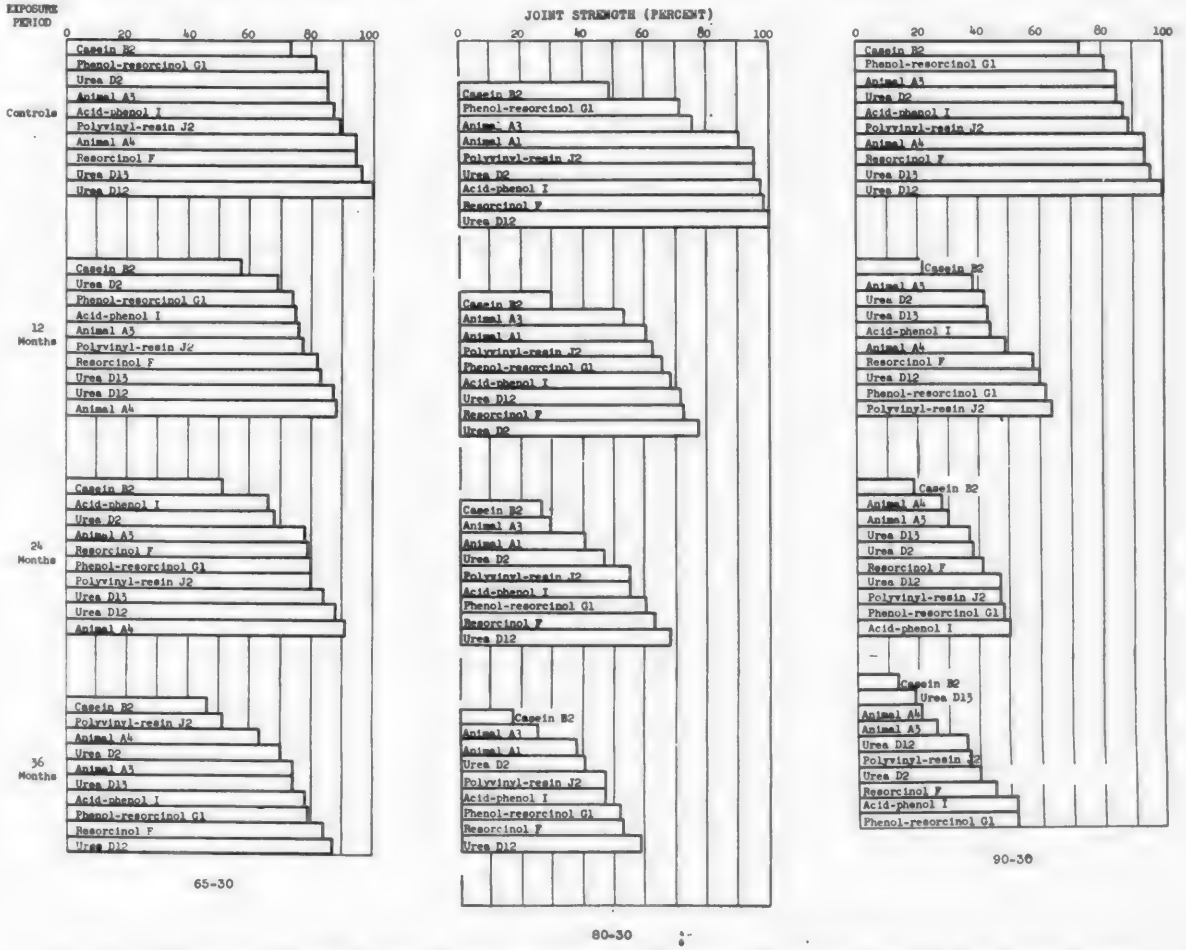

Figure 4.—Performance of various glues in mortise-and-tenon joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80 degrees F.

resorcinol resin retained the highest strength in the most severe exposure. In this latter exposure (90–30 cycle), however, the noncrazing urea was sixth from the top in strength retained. Casein glue retained least strength in all three exposures. Polyvinyl-resin glue was next to the bottom in performance in the mildest exposure, and fifth from the top in both of the most severe exposure cycles. The animal glues were in general in the lower range on the performance list, with the ordinary urea glues in about the same position or slightly above. The noncrazing urea resin (D12) appeared to have some advantage over the unmodified urea resins (D2 and D13) in the 65–30 and 80–30 cycles.

In the mortise-and-tenon joints the average strength retained after 36 months in the 90–30 percent relative humidity exposure varied from a low of 13 percent with the casein glue to a high of 52 percent with the acid-catalyzed phenol and the phenol-resorcinol. Although the highest percentage of strength retained with the mortise-and-tenon joint (52 percent) was lower than the highest retained with the dowel joint (63 percent), higher strength percentages generally were retained with the mortise-and-tenon joint than with the dowel joint.

Blocked Joints: Of all the joints tested, the blocked joint (fig. 5) was most affected by the exposures, with all of the glues losing considerable strength even in the mild 65–30 cycle. Because of the severe shrinking and swelling stresses that develop in this joint during even moderate changes in moisture content, retention of a high percentage of the original strength cannot be expected.

Among the adhesives used, the resorcinol-resin glue retained the highest level of strength in the two most severe cycles, but this level amounted to only 15 percent of the control strength after 36 months in the 90–30 cycle. The phenol-resorcinol glue was next in durability in this cycle, and the remaining eight glues retained from 0 to 4 percent of the control strength after 36 months of exposure. In the 80–30 relative humidity cycle the order of decreasing strength retention placed the glues as follows: resorcinol, acid-phenol, phenol-resorcinol, polyvinyl-resin, urea, casein, and animal glue.

Slip or Lock Joints: In the slip or lock joint (fig. 6) the strength retained after 36 months varied from 62 to 95 percent for the different glues in the 65–30 exposure, from 36 to 83 percent in the 80–30 exposure, and from 14 to 57 percent in the 90–30 exposure. The polyvinyl, acid-phenol, resorcinol, and phenol-resorcinol-resin glues in general retained the highest joint strength. These were followed by the ureas, the casein, and the animal glues in about that order, depending upon the particular exposure. The noncrazing urea (D12) gave about the same performance as the conventional urea-resin glues in this type of specimen.

End-grain-to-side-grain Joints: The resorcinol-resin glue was outstanding in performance in this type of joint, retaining 85 percent of the control strength after 36 months in the

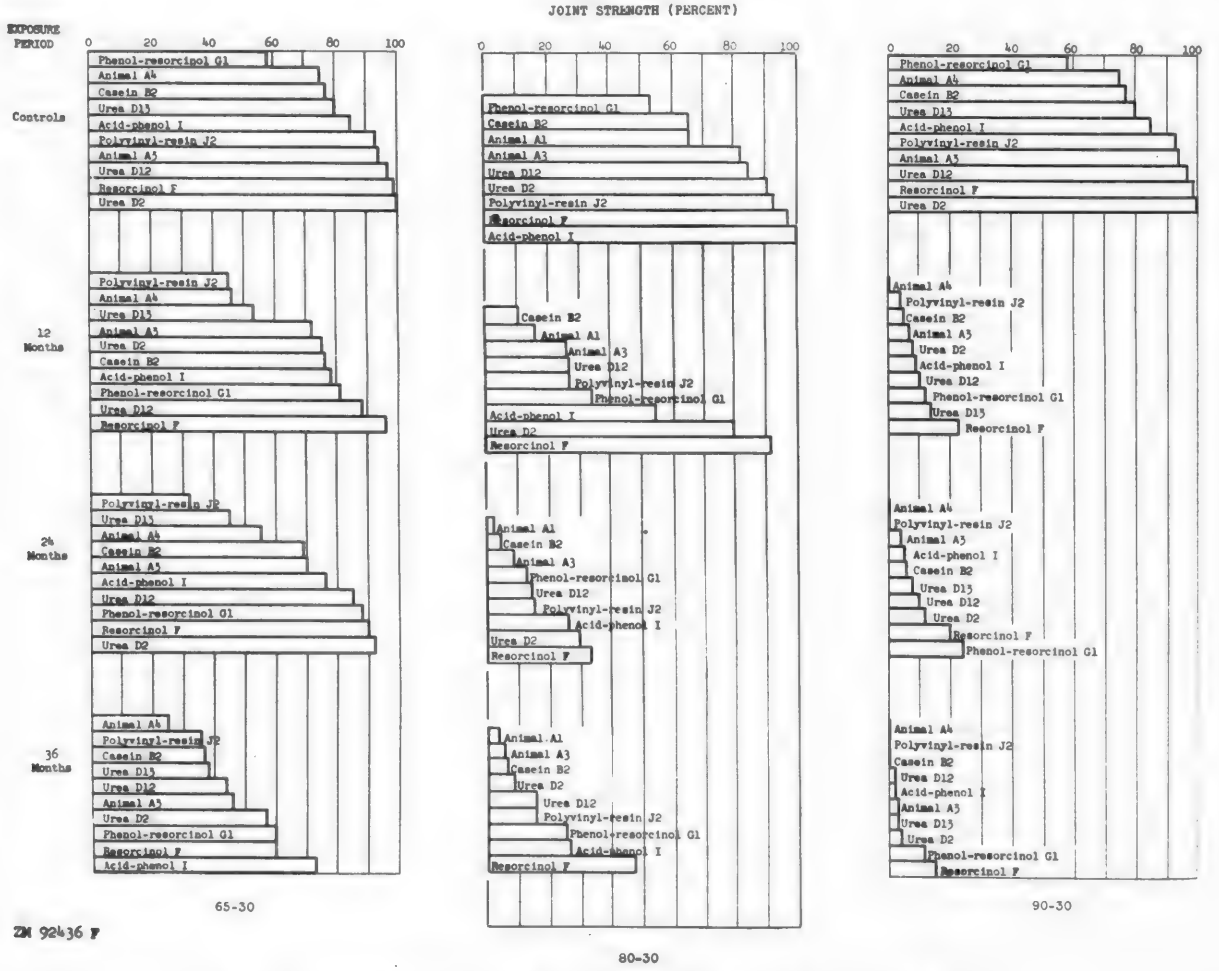

Figure 5.—Performance of various glues in blocked joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80 degrees F.

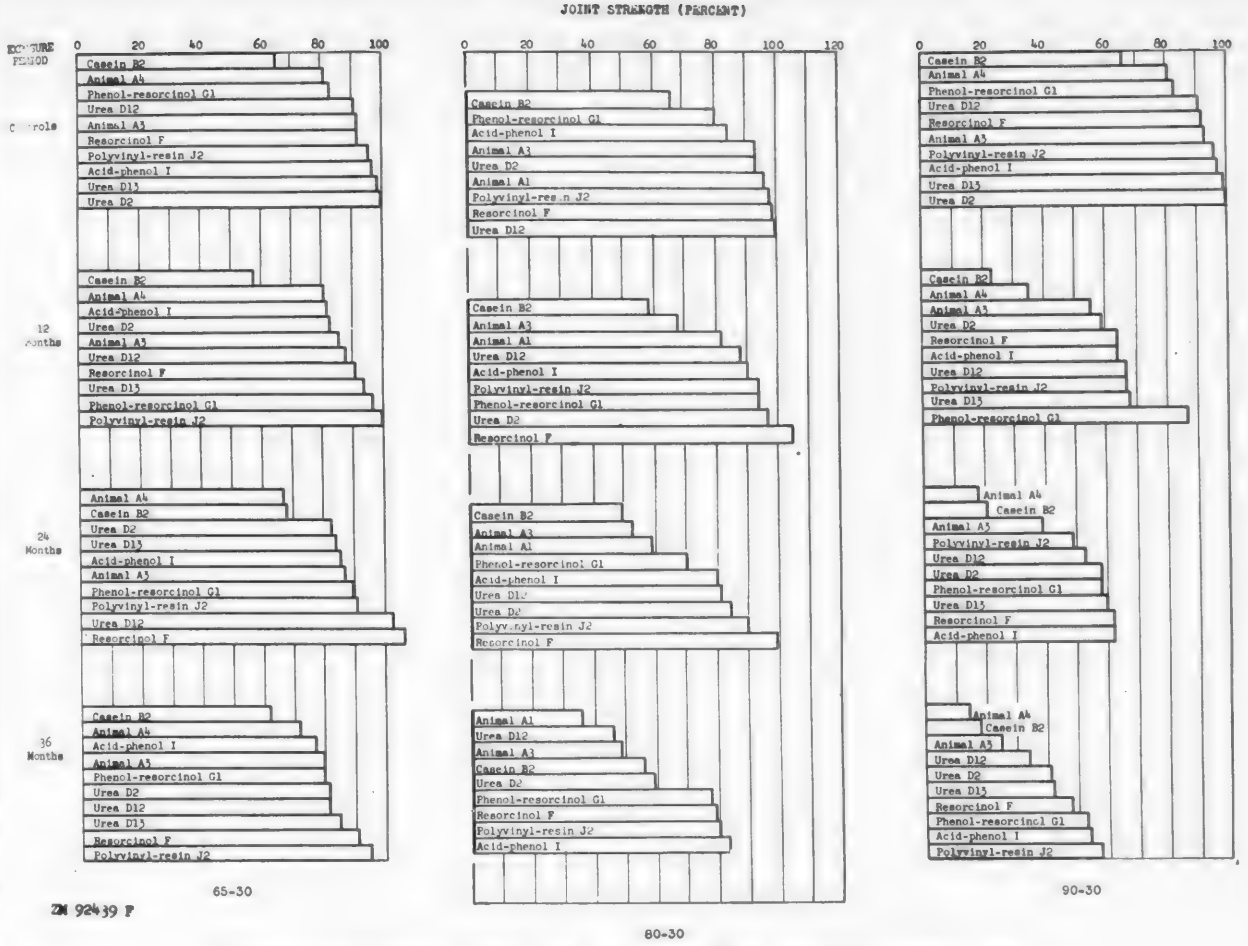

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Figure 6.—Performance of various glues in slip or lock joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80 degrees F.

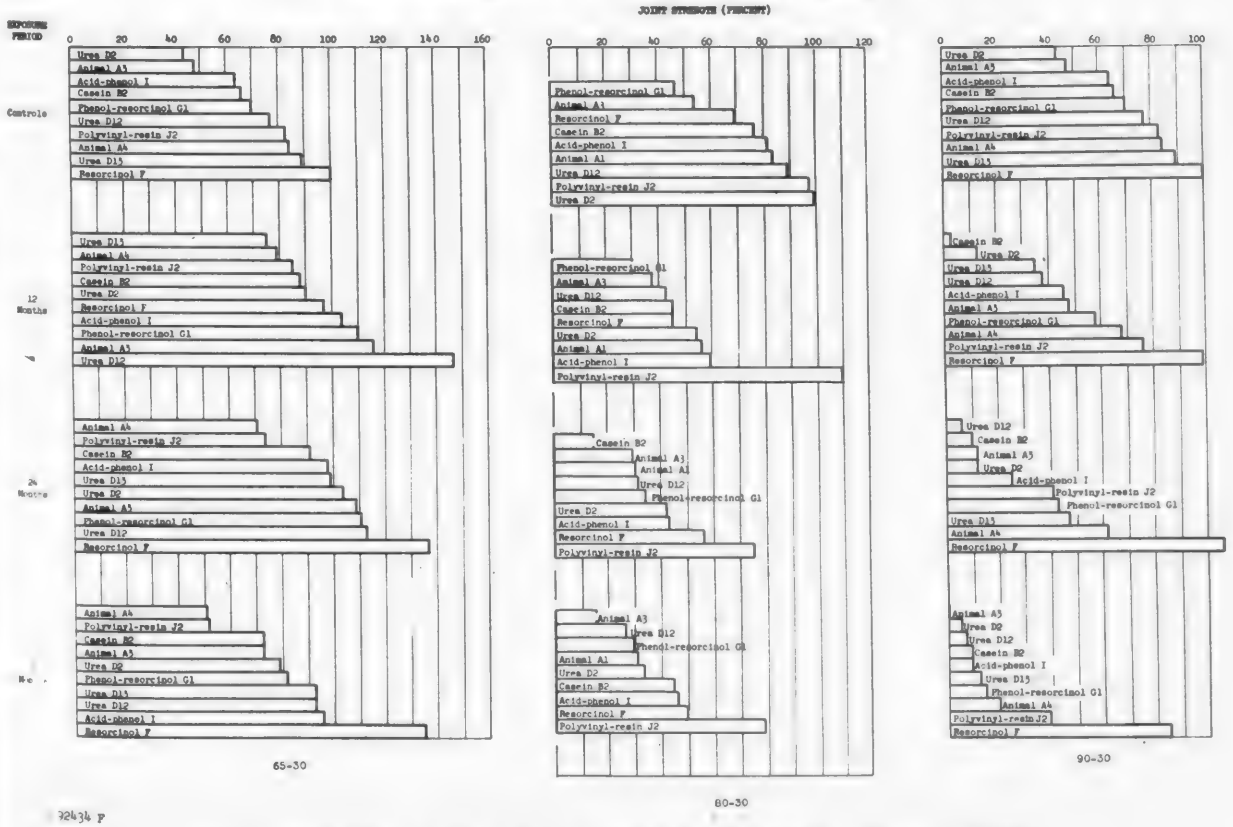

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Figure 7.—Performance of various glues in end-grain-to-side-grain joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80 degrees F.

most severe exposure (fig. 7). The other glues lost most of their joint strength after 36 months in this exposure, with the exception of the polyvinyl and the animal glue A4, which retained 39 and 20 percent, respectively, of the control strength. In the 80–30 cycle, the lowest strength retained was 15 percent (animal glue A4), and the order of decreasing strength retained after 36 months was about as follows: polyvinyl, resorcinol, acid-catalyzed phenol, casein, urea-resins, phenol-resorcinol, and animal glue. The performance of the glues was in much the same order in the 45° end-grain-to-side-grain joint, except that the phenol-resorcinol-resin glue rated the highest performance in this latter joint. In the more severe exposure cycle, the 45° end-grain-to-side-grain joints generally did not deteriorate so much as did the end-grain-to-side-grain joints, particularly with certain glues.

Side-grain-to-side-grain Joints: In the side-grain-to-side-grain joints (fig. 8) there were in general smaller losses of strength after 36 months of exposure than with any other type of joint.

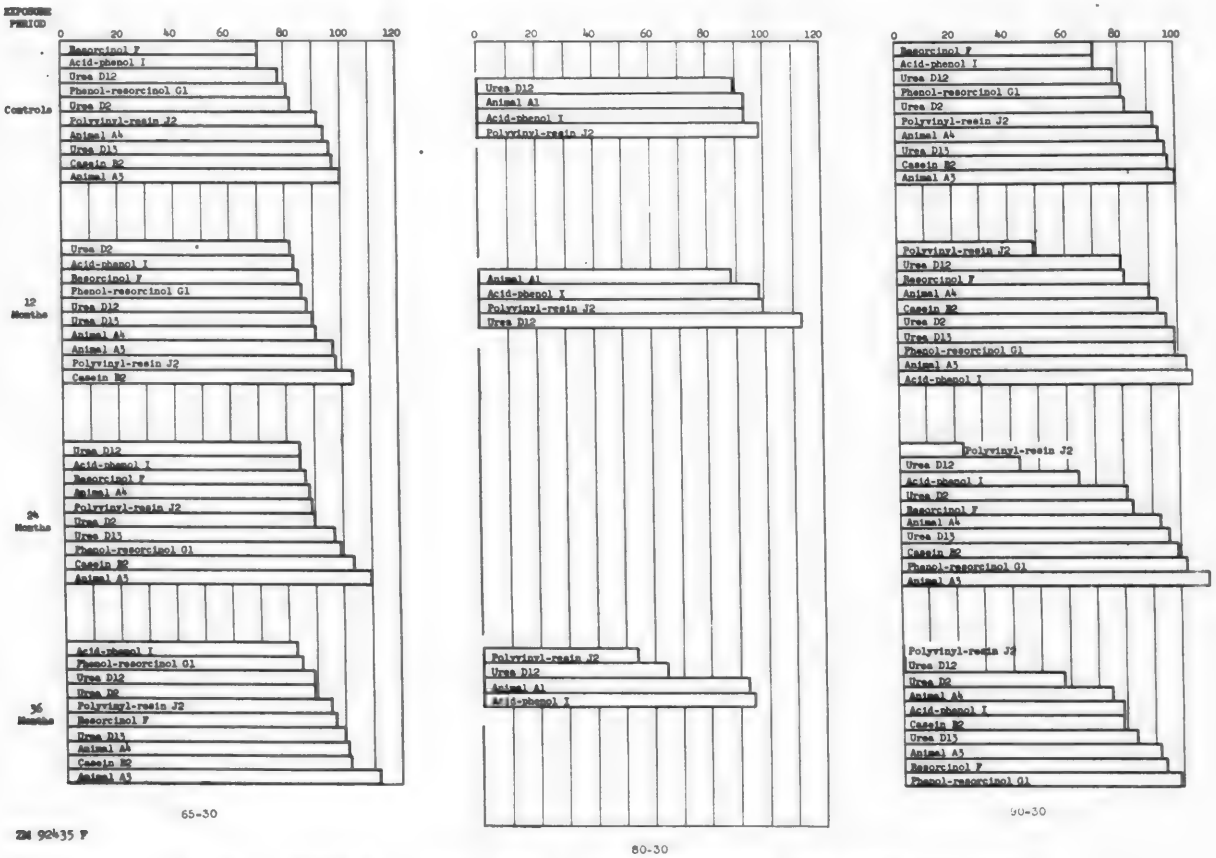

Figure 8.—Performance of various glues in side-grain-to-side-grain joints exposed to repeating cycles of 65–30, 80–30, and 90–30 relative humidity, all at 80 degrees F.

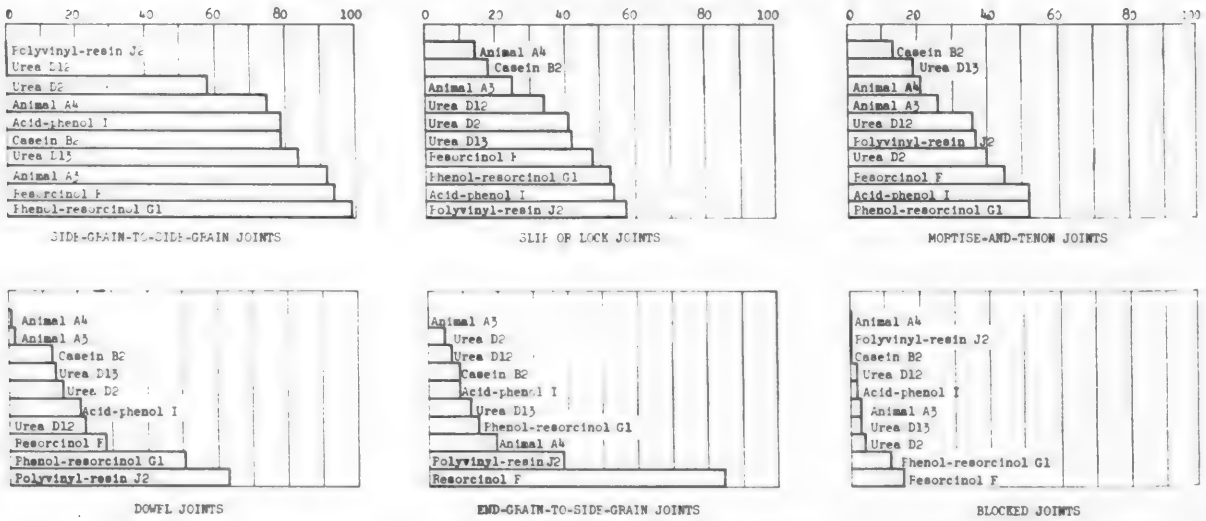

Figure 9.—Comparison of percentages of control strength values retained by different types of assembly joints after 36 months of exposure to a repeating cycle consisting of 4 weeks in air at 90 percent humidity followed by 4 weeks in air at 30 percent relative humidity, both at 80 degrees F. (Data from table 7.)

Two glues, the polyvinyl resin and the noncrazing urea resin (D12), however, had failed almost completely after 36 months in the 90–30 exposure. The remaining glues retained from a low of 58 percent (urea D2) to a high of 99 percent (phenol-resorcinol G1) in this cyclic exposure. The polyvinyl resin and the noncrazing urea resin (D12) also performed more poorly than the other two glues tested in the 80–30 cycle. (Only four glues were included with this type of joint in the 80–30 cycle.)

In the 65–30 exposure, the strength retained ranged from 83 percent (acid phenol I) to 112 percent (animal glue A3), and this included all adhesives used.

Comparison of the Durability of Different Types of Joints

A comparison of percentages of control strength values retained by six of the different types of assembly joints after 36 months of exposure to the 90–30 cycle is given in figure 9.

The side-grain-to-side-grain joints, in general, were the least affected by the cyclic exposures, even though two glues practically failed completely (in the 90–30 cycle). It was the only joint in which animal and casein glues performed well in the most severe exposure.

The other types of joints, in general, were in the following order of decreasing durability, based on the percentage of the control strength retained in the 90–30 exposure: slip or lock joint, 45° end-grain-to-side-grain joint, mortise-and-tenon joint, dowel joint, end-grain-to-side-grain joint, and blocked joint. The blocked joint was particularly low in durability.

Comparison of the Effects of Different Exposures

Effects of the three different exposure cycles on two of the types of joints tested are shown in figure 10. In the blocked joint which, as mentioned earlier, showed the poorest performance of all the joints tested, there was a severe drop in strength retained in the 80–30 exposure as compared with the 65–30 exposure; and, as would be expected, the drop in joint strength was still greater in the 90–30 exposure. In the mortise-and-tenon joint the decrease in joint strength with increased severity of exposure was also obvious, but the percentages of the control values retained were much greater than for the blocked joint.

Comparison of the Performance of Different Glues

The phenol-resorcinol-resin glue and the resorcinol-resin glue retained most

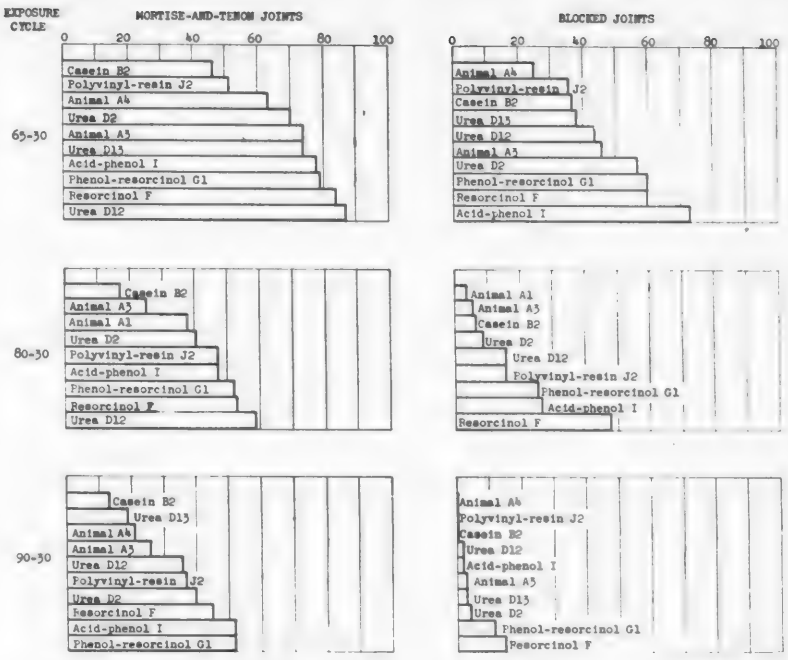

Figure 10.—Effect of different exposures on joint strength retained after 36 months in mortise-and-tenon and blocked joints. The exposures consisted of 4 weeks in air at 65, 80, or 90 percent relative humidity followed by 4 weeks in air at 30 percent relative humidity in a repeating cycle for 36 months. The temperature was 80 degrees F.

consistently the highest percentage of the control joint strength. The polyvinyl-resin emulsion glue was especially durable in the dowel joint and in the slip or lock joint, but performed poorly in the side-grain-to-side-grain joint, particularly in the 90–30 exposure. The animal glues and the casein glue were generally the least durable, except in the side-grain-to-side-grain joint, while the acid-catalyzed phenol-resin and the urea-resin glues were generally intermediate in most joints. The noncrazing urea (D12) performed somewhat better than the ordinary ureas in the dowel and in the mortise-and-tenon joints in some cycles, but performed definitely more poorly than the ordinary ureas in the side-grain-to-side-grain joint, particularly in the 90–30 cycle.

Animal glue has probably been the most widely used assembly glue, with the polyvinyl-resin emulsion glues coming into wider use in recent years. These two types develop a high degree of joint strength rather rapidly, which is an advantage because it permits early handling of the glued assembly without danger of injuring the joints.

Casein glue has generally been considered suitable for joints in products that would be used under conditions where the moisture content of the wood would not exceed 20 percent for repeated or prolonged periods. The basis for this has been data on laminated construction and thin plywood. In this study of assembly joints, however, the only joint in which casein glue performed well when the moisture content approached 20 percent was the side-grain-to-side-grain joint. In joints where the stresses due to differential shrinkage and swelling were more severe, casein glue did not perform well, particularly when the moisture content approached 20 percent.

Discussion

S. T. Pryce (John Widdicomb Co.): What glue is best for supported joint?

Mr. Selbo: That would depend somewhat on what type of service conditions you have in mind and probably also on the species. As you will notice from the data, some glues retained their strength much better than others. If a less dense species had been used the reduction in joint strength probably would have been less.

Wayne F. Hutchins (Baker Furniture Co.): What caused the deterioration in joint strength?

Mr. Selbo: Probably for most of the adhesives the loss in joint strength was caused by shrinkage and swelling stresses. For some, such as animal glue, the higher moisture contents probably had some effect.

Richard Blomquist (Forest Products Laboratory): Some glues softened.

Robert Snider (Franklin Glue Co.): How do stresses vary?

(Continued on page 220)

Table 3.--Performance[1] of various glues in different types of assembly joints exposed to a repeating cycle consisting of 4 weeks in air at 65 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type										
	A3[2] Animal	A4[3] Animal	B2 Casein with preservative added	D2 Room-temperature setting urea-resin	D12 Room-temperature setting (said to be noncreasing)	D13 Room-temperature setting urea-resin	F Resorcinol-resin	G1 Phenol-resorcinol-resin	I Room-temperature setting phenol-resin (acid-catalyzed)	J2 Polyvinyl-resin emulsion
Months										
Dowel joint										
0 (control)	77	80	63	74	84	79	100	96	91	99
6	77	81	63	77	93	72	92	94	89	96
12	67	84	63	71	86	69	85	91	76	101
18	62	85	64	71	80	76	82	77	74	112
24	73	74	54	74	73	79	78	78	72	96
36	69	84	69	69	80	62	77	91	72	96
Mortise-and-tenon joint										
0 (control)	96	94	71	94	100	96	94	81	87	89
6	94	93	74	79	96	93	87	84	83	84
12	76	88	67	69	87	83	82	74	75	77
18	82	88	71	76	91	81	75	80	83	83
24	78	91	71	68	87	84	79	80	66	80
36	74	83	67	70	87	74	84	79	73	51
Blocked joint										
0 (control)	94	75	77	100	97	85	99	98	85	93
6	92	83	82	107	105	78	95	98	104	41
12	77	80	76	75	88	83	96	91	78	49
18	74	87	71	100	97	84	100	98	95	53
24	73	85	69	91	85	85	90	94	76	32
36	68	85	57	87	84	83	90	85	73	36
Slip or lock joint										
0 (control)	93	81	65	100	91	99	92	83	97	96
6	91	87	69	98	93	86	90	92	87	97
12	86	81	68	82	88	94	91	97	82	100
18	85	72	65	87	93	85	88	85	86	93
24	87	67	68	83	103	84	107	90	86	91
36	80	72	62	82	82	85	91	80	77	95
End-grain-to-side-grain joint										
0 (control)	48	52	66	44	77	83	110	70	64	83
6	90	71	64	86	100	88	129	88	85	71
12	116	79	98	96	147	76	97	110	104	85
18	94	75	91	89	125	110	140	102	106	79
24	109	71	91	94	113	99	117	111	98	74
36	73	51	73	79	93	93	135	82	96	52
45-degree, end-grain-to-side-grain joint										
0 (control)	74	75	66	67	76	88	100	86	67	76
6	87	82	104	94	110	118	111	101	105	76
12	113	95	111	114	14	96	89	121	113	97
18	112	80	124	116	147	107	127	140	120	97
24	98	80	98	96	126	107	120	129	96	95
36	91	98	97	76	83	89	100	114	92	65
Side-grain-to-side-grain joint										
0 (control)	102	94	97	85	78	96	71	81	71	92
6	104	89	108	95	94	102	106	97	109	90
12	97	91	104	82	88	90	85	89	82	98
18	95	83	97	91	92	97	100	89	96	80
24	110	89	114	90	85	97	88	99	87	89
36	112	101	102	89	89	100	97	85	83	95

[1] For each type of joint the highest average control strength developed by any one glue (table 2) was chosen as a basis for comparison, and the test values for all other glues throughout the exposure period were expressed as a percentage of this basis. (In the dowel joint the control strength of the resorcinol glue F was the basis for comparison, in the mortise-and-tenon joint, the urea-resin D12, etc.).

[2] Animal glue with a proprietary preservative and a separately applied proprietary compulsant.

[3] Animal glue plus 0.5 part of an ethyl mercury phosphate preservative and a compulsant (10 percent formaldehyde solution) separately applied.

Table 2.--Results[1] of tests[2] of assembly joints made with several glues and exposed to a repeating cycle consisting of 4 weeks in air at 65 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type									
	A3[3] Animal	A4[4] Animal	B2 Casein with preserv-ative added	D2 Room-temp-erature-setting urea-resin	D12 Room-temp-erature-setting (said to be noncreasing)	D13 Room-temp-erature-setting urea-resin	F Resorcinol-resin	G1 Phenol-resorcinol-resin	I Room-temp-erature-setting phenol-resin (acid-catalyzed)	J2 Polyvinyl-resin emulsion
Months										
Dowel joint										
0 (control)	886-12	805- 6	714- 6	902-18	965-23	912-14	1,158-24	1,046-24	1,052-44	1,131-52
6	857-31	613- 3	694- 6	803-14	1,077-58	833-30	1,065-35	1,090-38	985-46	1,114-56
12	722-17	496- 3	683-12	750- 6	984-61	801-19	984-36	1,056-37	875-79	1,166-32
18	928-19	641-14	732-16	817-15	923-52	876-46	953-39	886-50	858-61	1,295-44
24	840-30	698-41	623-21	632-12	860-31	846-27	914-45	909-29	829-56	1,115-41
36	686-25	466- 5	763-22	569-22	922-54	720-31	887-19	1,054-52	839-75	1,113-47
Mortise-and-tenon joint										
0 (control)	2,569-10	2,841-15	2,193- 5	2,561-24	3,016-32	2,888- 4	2,828- 9	2,433-16	2,631-19	2,691-12
6	2,519- 9	2,788-12	1,941- 0	2,388- 9	2,888-20	2,796- 9	2,632- 9	2,494-12	2,489- 9	2,521-11
12	2,288-10	2,646- 8	1,726- 2	2,066- 6	2,622-11	2,508- 6	2,465- 8	2,228- 2	2,248-16	2,308- 5
18	2,469-25	2,574-14	1,850- 0	2,126-13	2,749-19	2,458- 1	2,856- 2	2,584- 9	2,515-19	2,512- 7
24	2,355- 8	2,756-17	1,548- 3	2,050-11	2,666-67	2,536- 3	2,392- 9	2,420-10	1,996-34	2,404- 7
36	2,222- 3	1,904- 8	1,374- 1	2,108-11	2,620- 9	2,246- 2	2,520- 8	2,380-21	2,344-23	1,524- 1
Blocked joint										
0 (control)	1,978-18	1,583-10	1,633-14	2,110-18	2,039-18	1,689-10	2,082-37	1,215- 0	1,796-12	1,955-11
6	2,002-19	1,247-12	1,728-13	2,261-18	2,220- 3	1,639-24	2,007-22	2,069- 3	2,191-45	873- 8
12	1,589-10	970- 8	1,601-13	1,574-13	1,860-18	1,110-14	2,024-41	1,705- 3	1,643- 3	957-15
18	1,774-83	990- 1	1,293- 9	2,451-29	2,055-24	1,360-19	2,119-23	1,903- 0	2,010-13	1,114- 1
24	1,470-10	1,159- 7	1,454- 3	1,950- 6	1,804-12	957-23	1,890-58	1,851- 2	1,609- 8	680- 4
36	978-22	534- 7	789- 2	1,213-15	928- 1	799-18	1,265-12	1,256-10	1,541-11	762- 0
Slip or lock joint										
0 (control)	1,243-38	1,087-17	881- 7	1,349-56	1,230-56	1,332-54	1,244-34	1,119- 9	1,306-38	1,200-47
6	1,246-13	1,022-20	931- 6	1,209-52	1,258-39	1,158-69	1,215-22	1,239-29	1,174-51	1,307-30
12	1,162-39	1,097-29	785-17	1,114-22	1,182-60	1,272-38	1,222-32	1,312-16	1,108-68	1,149-45
18	1,146-32	971- 7	881- 2	1,172-30	1,256-59	1,148-43	1,181-41	1,146-27	1,156-41	1,260-28
24	1,179-30	909-33	923- 4	1,121-39	1,386-35	1,130-58	1,441-21	1,220-12	1,166-49	1,222-27
36	1,076-35	968-32	837-10	1,108-28	1,108-77	1,144-44	1,233-35	1,081-42	1,036-54	1,289-36
End-grain-to-side-grain joint										
0 (control)	240- 4	419-11	388- 0	219- 0	383- 2	446- 2	499- 5	351- 0	319- 2	416- 5
6	451-21	352-15	462- 0	429- 1	497-24	440- 9	646- 5	439- 1	422- 5	355- 3
12	578- 5	396-25	438- 0	449- 1	733-19	374-10	482- 5	587- 1	519-10	428- 2
18	487- 7	373-12	458- 0	448- 0	685-12	547-16	699-24	511- 0	530- 5	392- 1
24	544-13	355- 2	496- 3	517- 3	563- 9	493- 3	684- 6	553- 6	488-13	371-13
36	363-23	257-10	364- 0	394- 0	464- 4	463- 1	673- 5	411- 0	478- 8	258- 1
45-degree, end-grain-to-side-grain joint										
0 (control)	246- 1	348-27	303- 6	252-10	345-34	403-32	456-17	393-12	304- 2	346-26
6	398-10	899-31	476- 6	458-11	589-21	536-12	505-21	461-45	478-35	348-18
12	509-17	389- 4	505- 3	539-24	594- 9	436-41	407-10	554-27	515-13	444-22
18	518-24	378- 7	564- 6	589-21	627-24	490-51	578-63	640-80	545-34	441-25
24	446-39	363- 2	439-23	388- 9	456-32	487-10	545-44	495-68	438-53	435-19
36	389- 4	165- 1	396-12	345-20	380-22	408-16	456-24	521- 3	420-58	396-11
Side-grain-to-side-grain joint										
0 (control)	3,121-91	2,983-73	3,039-48	2,562-62	2,438-40	2,984-74	2,230-68	2,519- 7	2,213-86	2,876-74
6	3,239-91	2,498-79	3,360-90	2,964-86	3,009-68	3,179-76	3,294-55	3,014-39	3,416-65	2,811-71
12	3,021-79	2,834-86	3,237-59	2,568-59	2,783-45	2,798-83	2,651-58	2,676-42	2,577-58	3,070-51
18	2,980-81	2,559-81	3,023-57	2,843-72	2,876-56	3,041-69	3,113-87	2,773-30	3,006-76	2,485-34
24	3,485-76	2,778-77	3,247-73	2,822-84	2,845-38	3,088-54	2,733-99	3,086-47	2,739-65	2,791-68
36	3,498-83	3,140-62	3,179-73	2,771-73	2,792-54	3,111-87	3,031-44	2,653-42	2,583-69	2,958-59

[1] In this table the value before the dash is the average breaking load in pounds (except for the side-grain-to-side-grain joint, which is in pounds per square inch); the value after the dash is the average estimated wood failure in percent. Each control value is the average for 10 specimens; other values are the average for 5 specimens.

[2] The specimens were tested at the end of the low-humidity part of the cycle.

[3] Animal glue with a proprietary preservative and a separately applied proprietary compulsant.

[4] Animal glue plus 0.5 part of an ethyl mercury phosphate preservative and a compulsant (10 percent formaldehyde solution) separately applied.

Table 5.--Performance[1] of various glues in different types of assembly joints exposed to a repeating cycle consisting of 4 weeks in air at 80 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type								
	A1 Animal glue	A3 Animal with a proprietary preservative and a separately applied proprietary coagulant	B2 Casein with preservative added	D2 Room-temperature setting urea-resin	D12 Room-temperature setting urea-resin (said to be noncrazing)	F Resorcinol resin	G1 Phenol-resorcinol resin	I Room-temperature setting phenol-resin (acid-catalyzed)	J2 Polyvinyl-resin emulsion
Months									
Dowel joint									
0 (control)	64	60	45	58	66	79	68	76	100
6	30	31	22	45	40	67	50	6	86
12	20	23	18	39	22	47	45	13	79
18	7	16	17	36	24	44	31	2	69
24	11	10	9	35	20	45	34	6	65
36	4	6	4	24	19	53	41	7	69
Mortise-and-tenon joint									
0 (control)	90	75	48	95	100	98	71	97	95
6	60	64	28	74	81	87	77	82	68
12	60	53	30	77	71	72	65	68	62
18	59	41	23	56	66	68	61	60	55
24	40	29	26	46	67	62	59	54	54
36	38	17	25	40	59	52	51	47	47
Blocked joint									
0 (control)	66	83	56	91	85	98	54	100	93
6	26	52	21	75	38	68	30	83	28
12	16	26	11	80	27	92	34	55	27
18	13	12	8	41	20	87	24	58	16
24	2	9	4	29	14	33	13	26	16
36	3	5	6	8	15	47	25	26	15
Slip or lock joint									
0 (control)	90	86	66	94	100	99	81	84	97
6	83	70	71	89	103	104	85	90	78
12	83	68	59	98	89	106	95	91	95
18	72	75	47	95	85	103	80	97	83
24	69	64	49	87	82	99	71	81	89
36	39	48	56	69	46	79	77	83	80
End-grain-to-side-grain joint									
0 (control)	94	76	78	100	91	71	48	83	99
6	58	61	54	102	67	78	55	69	109
12	58	38	46	55	44	46	34	67	111
18	41	78	43	55	38	44	21	54	53
24	35	40	25	42	32	57	34	43	76
36	39	19	44	33	27	49	32	46	79
Side-grain-to-side-grain joint									
0 (control)	95				91			95	110
6	98				92			78	113
12	90				115			100	101
18	91				86			88	98
36	93				64			95	54

[1] For each type of joint the highest average control strength developed by any one glue (table 4) was chosen as a basis for comparison, and the test values for all other glues throughout the exposure period were expressed as a percentage of this basis.

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Table 4.--Results[1] of tests[2] of assembly joints made with several glues and exposed to a repeating cycle consisting of 4 weeks in air at 80 percent relative humidity, followed by 4 weeks in air at 30 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type								
	A1 Animal glue	A3 Animal with a proprietary preservative and a separately applied proprietary coagulant	B2 Casein with preservative added	D2 Room-temperature setting urea-resin	D12 Room-temperature setting urea-resin (said to be noncrazing)	F Resorcinol resin	G1 Phenol-resorcinol resin	I Room-temperature setting phenol-resin (acid-catalyzed)	J2 Polyvinyl-resin emulsion
Months									
Dowel joint									
0 (control)	878-14	824-10	616- 2	797-19	903-26	1,084-35	942-26	1,046-30	1,376-27
6	410- 0	432- 0	306- 0	612-11	546- 9	920-27	682- 7	76- 0	1,178-74
12	274-14	312- 0	242- 0	538-16	296- 1	646-14	618- 9	176- 0	1,092-37
18	92- 0	208- 1	238- 2	492-12	330- 1	592-10	422-20	32- 0	944-22
24	152- 0	134- 0	126- 0	478- 0	268- 0	606- 5	462-10	88- 0	900-19
36	60- 0	80- 0	60- 0	336- 4	264- 0	736-14	568-15	92- 2	944-26
Mortise-and-tenon joint									
0 (control)	2,494- 6	2,057- 8	1,331- 0	2,627-11	2,757-10	2,705- 8	1,959- 4	2,684-14	2,632- 3
6	1,908- 3	1,772- 4	768- 0	2,036- 4	2,220- 9	2,388- 6	1,992- 5	2,268-10	1,880- 0
12	1,664- 3	1,458- 1	844- 0	2,118-10	1,964- 4	1,972-11	1,800- 4	1,864-12	1,696- 0
18	1,636-12	1,130- 3	647- 1	1,536- 8	1,825- 9	1,864- 7	1,680-15	1,642-19	1,526- 1
24	1,122- 2	818- 1	726- 1	1,868- 0	1,836- 4	1,712- 3	1,618- 3	1,474- 7	1,484- 1
36	1,036- 0	462- 0	688- 1	1,116- 2	1,640-16	1,562-10	1,556- 8	1,286-23	1,284- 1
Blocked joint									
0 (control)	1,338-11	1,687-17	1,328- 5	1,846-10	1,723-17	1,983-10	1,100- 0	2,026-18	1,875-15
6	514- 2	1,049-11	420- 1	1,523-17	771- 3	1,383-10	609- 5	1,674-37	523- 0
12	318- 6	526-14	225- 0	1,616-15	547- 3	1,859-15	690- 1	1,107-22	557- 0
18	272- 1	650- 1	169- 0	838- 9	399- 3	1,757-15	488- 4	1,459-59	321- 0
24	44- 0	191- 2	93- 0	585-15	280- 2	659-58	258- 4	532-27	315- 0
36	68- 0	103- 0	129- 0	158- 0	304- 2	954-57	504- 6	520-34	313- 1
Slip or lock joint									
0 (control)	1,256-20	1,117-15	869-10	1,232-34	1,307-36	1,294-44	1,061- 8	1,228-20	1,269-38
6	1,212-45	916-44	924- 1	1,161-38	1,346-26	1,360-61	1,190-10	1,173-59	995-15
12	1,089- 5	890-12	769- 5	1,278-33	1,160-39	1,387-61	1,239- 9	1,195-39	1,235-17
18	935-22	984- 9	618- 4	1,247-13	1,118-11	1,349-71	1,051- 3	1,268-12	1,089- 8
24	765-13	702- 8	656- 3	1,117-22	1,073-24	1,290-31	925- 5	1,065-26	1,180- 4
36	472- 4	623- 1	729- 2	770-12	603- 3	1,026-39	1,007- 9	1,087-37	1,047- 8
End-grain-to-side-grain joint									
0 (control)	431- 2	284- 7	397- 3	508-13	464-28	359- 7	244- 1	422- 2	500-24
6	255- 3	312- 4	275- 0	519-39	341-11	398-21	278- 0	350- 0	656-15
12	291- 1	191- 5	231- 1	280- 1	225-11	232- 5	175- 0	311-20	564- 8
18	310- 1	394- 5	216- 0	276- 2	192- 1	225- 8	105- 0	302- 1	267- 1
24	158- 2	157- 5	75- 1	211- 1	164- 1	290-27	173- 1	220- 6	384- 4
36	148- 0	76- 0	226- 0	166- 1	138- 0	250- 2	163- 0	235- 1	404- 1
Side-grain-to-side-grain joint									
0 (control)	2,795-93			2,679-55				2,804-44	2,941- 9
6	2,889-87			2,698-65				2,307-78	3,335-41
12	2,662-86			3,393-59				2,937-73	2,982- 6
18	2,675-100			2,524-55				2,573-74	2,882-14
36	2,737-80			1,884-43				2,787-83	1,568- 1

[1] In this table the value before the dash is the average breaking load in pounds (except for the side-grain-to-side-grain joint, which is in pounds per square inch); the value after the dash is the average estimated wood failure in percent. Each control value is the average for 10 specimens; other values are the average for 5 specimens.

[2] The specimens were tested at the end of the low-humidity part of the cycle.

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Table 7.--Performance[1] of various glues in different types of assembly joints exposed to a repeating cycle consisting of 4 weeks in air at 90 percent relative humidity, followed by 4 weeks in air at 5 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type										
	A3[2] Animal	A4[2] Animal	B2 Casein with preservative added	D2 Room-temperature setting urea-resin (said to be noncrazing)	D12 Room-temperature setting urea-resin	D14 Room-temperature setting urea-resin	F Resorcinol resin	G1 Phenol-resorcinol resin	I Room-temperature setting phenol-resin (acid-catalyzed)	J4 Polyvinyl resin emulsion
Months										
Dowel joint										
0 (control)	77	70	62	78	84	79	100	90	91	98
6	20	18	25	41	54	49	59	64	64	81
12	20	11	14	34	37	30	41	73	23	76
18	17	14	19	23	29	25	29	70	21	73
24	4	6	13	22	28	17	42	59	17	63
36	2	1	13	16	22	14	28	51	21	63
Mortise-and-tenon joint										
0 (control)	85	94	73	85	100	96	94	81	87	89
6	54	60	25	54	75	73	60	72	67	50
12	38	49	22	42	60	43	58	62	44	64
18	47	36	22	39	59	44	47	51	59	47
24	30	28	19	38	47	37	41	48	50	47
36	26	21	13	40	36	19	45	52	52	37
Blocked joint										
0 (control)	94	75	77	100	97	87	99	58	85	93
6	12	0	6	36	10	17	41	12	12	10
12	7	0	5	8	10	14	23	12	9	4
18	9	0	4	12	7	14	33	11	10	5
24	4	0	6	12	10	8	20	24	5	0
36	3	0	0	4	2	5	15	11	2	0
Slip or lock joint										
0 (control)	92	81	65	100	91	99	92	83	97	96
6	59	51	39	93	81	79	84	86	80	67
12	35	35	23	59	67	68	64	87	64	67
18	47	17	26	71	55	61	52	70	61	54
24	39	18	21	58	53	64	62	58	62	49
36	25	14	18	41	34	42	48	53	54	57
End-grain-to-side-grain joint										
0 (control)	48	84	66	44	77	89	100	70	64	83
6	52	71	31	52	39	79	108	61	39	74
12	48	68	3	23	38	35	99	58	46	76
18	40	51	8	17	27	44	111	48	25	43
24	12	62	10	12	6	47	106	43	25	41
36	0	20	9	5	7	12	85	14	9	39
45-degree, end-grain-to-side-grain joint										
0 (control)	54	75	66	55	76	88	100	86	67	76
6	90	61	45	81	92	103	119	114	73	89
12	57	59	22	59	71	67	111	118	79	103
18	55	11	19	49	50	66	117	128	88	100
24	4	10	11	59	30	55	89	93	62	91
36	0	0	7	21	14	43	82	90	44	57
Side-grain-to-side-grain joint										
0 (control)	100	94	97	82	78	96	71	81	71	92
6	109	90	95	88	80	115	97	105	92	54
12	107	90	93	96	80	99	81	99	105	49
18	100	82	90	89	65	103	94	96	95	27
24	111	93	99	81	43	96	83	102	64	23
36	92	75	79	58	1	84	94	99	79	0

[1] For each type of joint the highest average control strength developed by any one glue (table 6) was chosen as a basis for comparison, and the test values for all other glues throughout the exposure period were expressed as a percentage of this basis.

[2] Animal glue with a proprietary preservative and a separately applied proprietary coagulant.

[3] Animal glue plus 0.5 part of an ethyl mercury phosphate preservative and a coagulant (10 percent formaldehyde solution) separately applied.

Table 6.--Results[1] of tests[2] of assembly joints made with several glues and exposed to a repeating cycle consisting of 4 weeks in air at 90 percent relative humidity, followed by 4 weeks in air at 5 percent relative humidity, both at 80° F.

Exposure time	Glue symbol and type									
	A3[3] Animal	A4[3] Animal	B2 Casein with preservative added	D2 Room-temperature setting urea-resin (said to be noncrazing)	D12 Room-temperature setting urea-resin	D14 Room-temperature setting urea-resin	F Resorcinol resin	G1 Phenol-resorcinol resin	I Room-temperature setting phenol-resin (acid-catalyzed)	J4 Polyvinyl resin emulsion
Months										
Dowel joint										
0 (control)	886-12	805- 6	714- 6	902-18	966-23	912-14	1,158-24	1,046-24	1,052-44	1,101-[illegible]
6	226-20	204- 3	295- 4	471- 1	626-28	447- 2	670-11	746-11	396-29	934-[illegible]
12	232- 3	125- 1	167- 5	394- 7	429-19	351-11	479-21	840-14	241-13	886-[illegible]
18	192- 1	104- 2	216- 6	268- 6	334- 3	287- 2	347- 4	812-[illegible]	240- 3	847-[illegible]
24	43- 0	71- 0	155- 5	251- 9	321- 3	195- 2	489- 7	679-[illegible]	200- 6	749-[illegible]
36	20- 0	14- 0	147- 4	184- 2	255-25	158- 0	324- 9	588-20	245-19	744-[illegible]
Mortise-and-tenon joint										
0 (control)	2,569-10	2,841-15	2,193- 5	2,561-24	3,016-32	2,888- 4	2,828- 9	2,433-16	2,631-19	2,691-[illegible]
6	1,614- 3	1,813-16	745- 0	1,628-10	2,261- 7	2,216- 8	1,808- 2	2,164- 1	1,538- 4	1,538- 1
12	1,156- 2	1,470- 4	656- 1	1,256-10	1,808-11	1,301- 2	1,741- 2	1,787- 3	1,318- 4	1,920- 0
18	1,412- 2	1,095- 0	652- 0	1,162- 5	1,778- 7	1,324- 2	1,419- 2	1,548- 1	1,769-10	1,430- [illegible]
24	900- 1	844- 0	586- 0	1,152- 7	1,404-21	1,120- 1	1,248- 0	1,458- 5	1,516-28	1,424- [illegible]
36	772- 0	624- 5	394- 0	1,218- 1	1,100- 0	566- 0	1,344- 1	1,556- 5	1,568-10	1,176- 0
Blocked joint										
0 (control)	1,978-18	1,583-10	1,633-14	2,110-18	2,039-18	1,689-10	2,082-37	1,215- 0	1,796-12	1,955-11
6	249- 1	0- 0	126- 0	756-18	203- 3	351- 5	872-20	258- 0	249- 1	210- 0
12	155- 1	10- 0	112- 0	177- 1	212- 3	305- 9	478-37	249- 4	186- 4	92- 0
18	200- 3	0- 0	87- 3	243- 6	139- 2	298- 6	706-23	239- 2	214- 8	96- 0
24	90- 0	0- 0	129- 0	257- 9	219- 0	164- 6	412-18	509- 4	108- 1	0- 0
36	67- 0	0- 0	9- 0	77- 3	39- 1	66- 0	311-16	240-10	47-12	0- 0
Slip or lock joint										
0 (control)	1,243-38	1,087-17	881- 7	1,349-56	1,230-56	1,332-54	1,244-34	1,119- 9	1,306-38	1,290-47
6	792- 7	684- 6	526- 0	1,259-55	1,096-30	1,071-36	1,129-34	1,161-12	1,084-32	907-13
12	737- 9	471- 1	311- 0	798-18	898-28	923-53	870- 4	1,178-22	869-11	902-10
18	640- 5	228- 0	353- 1	956-33	747-18	823-47	706- 6	948- 8	817-22	731- 3
24	526- 1	237- 0	289- 0	785- 5	717- 9	813-15	840-13	788- 1	831-15	659-10
36	338- 1	184- 3	244- 1	549- 0	458- 1	560-22	648-11	709-24	734-26	770-10
End-grain-to-side-grain joint										
0 (control)	240- 4	419-11	328- 0	219- 0	383- 2	446- 2	499- 5	351- 0	319- 2	416- 5
6	259- 0	353-17	155- 0	258- 0	197- 1	395- 3	538-24	306- 0	197- 0	370-15
12	239- 0	339-11	14- 0	115- 0	188- 0	174- 0	493- 7	289- 3	228- 6	379- 0
18	202- 4	254- 2	41- 0	86- 0	133- 1	222- 3	553-32	238- 4	123- 1	214- 1
24	61- 0	307- 7	50- 0	60- 2	28- 0	233- 3	530- 4	214- 6	125-10	203- 1
36	0- 0	99- 0	45- 0	23- 0	33- 0	59- 0	422- 4	71- 3	44- 9	193- 0
45-degree, end-grain-to-side-grain joint										
0 (control)	246- 1	342-27	303- 6	252-10	345-34	403-32	456-17	393-12	304- 2	346-26
6	409- 5	276-15	204- 0	371- 9	418-40	468-10	542-14	521-59	335- 9	405-21
12	258- 5	269-16	101- 1	269- 5	323-13	304- 2	508-31	536-37	361-23	471-31
18	249- 7	51- 0	86- 0	225- 4	228- 3	302-17	532-42	582-81	403-25	458-17
24	16- 0	47- 2	51- 0	269- 7	136- 1	251- 2	407-26	423-54	283-14	416- 7
36	0- 0	0- 0	33- 0	98- 2	65- 2	195- 0	374- 9	412-10	202- 8	259- 1
Side-grain-to-side-grain joint										
0 (control)	3,121-91	2,923-73	3,039-48	2,562-62	2,438-40	2,984-74	2,230-68	2,519- 7	2,213-26	2,874-74
6	3,394-75	2,795-86	2,978-56	2,756-53	2,495- 6	3,601-87	3,017-81	3,280-57	2,859-56	1,692-12
12	3,202-88	2,821-85	2,901-55	3,007-88	2,482-25	3,098-84	2,524-54	3,105-53	3,265-70	1,525-14
18	3,129-87	2,561-87	2,824-44	2,786-67	2,040-36	3,210-64	2,947-78	2,991-56	2,975-59	830- 3
24	3,459-74	2,902-81	3,095-66	2,527-63	1,329-28	3,007-94	2,585-67	3,181-43	2,011-28	725-11
36	2,857-70	2,335-82	2,463-43	1,809-37	30- 0	2,622-67	2,941-52	3,088-44	2,473-67	0- 0

[1] In this table the value before the dash is the average breaking load in pounds (except for the side-grain-to-side-grain joint, which is in pounds per square inch); the value after the dash is the average estimated wood failure in percent. Each control value is the average per 10 specimens; other values are the average per 5 specimens.

[2] The specimens were tested at the end of the low-humidity part of the cycle.

[3] Animal glue with a proprietary preservative and a separately applied proprietary coagulant.

[4] Animal glue plus 0.5 part of an ethyl mercury phosphate preservative and a coagulant (10 percent formaldehyde solution) separately applied.

TECHNICAL SESSION III—Tues., June 16, 1953, 9:00 A.M.

Subject: Chemical Utilization

Chairman: Reavis C. Sproull

Recorder: Walton Smith

Pulp and Paper: Tools for Hardwood Utilization

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Hardwoods are a detriment to the growth of more desirable softwoods in important forested areas. Yet they represent one of the last frontiers of wood supplies for several of the forest products industries, importantly the pulp and paper industry. The processes of this industry may be considered tools for utilizing these unwanted hardwoods. All of the conventional pulping methods and the newer semichemical methods can be used with hardwoods, although some are better than others.

The semichemical processes, including the recently developed cold soda process; the coarse fiber processes for making felt and wallboard stocks; the sulfate process, including its refinement of prehydrolysis; and the groundwood process with its variation in the chemigroundwood process, are described as being especially suitable for hardwoods. Examples of the successful application of these methods in research at the Forest Products Laboratory are given. The possibilities of the sulfite and soda processes are also discussed.

Introduction

IMPERFECT BALANCE in the growth-drain relations of the forests in this country has caused much "viewing with alarm" during the long history of wood utilization—and with considerable justification. One part of the picture that is still causing distress among foresters is the over-growth of the hardwoods, especially the so-called weed types. It is well known that they are a detriment to the growth of the more valuable softwoods. Control, or attempted control, has sometimes taken the form of disposal at some cost instead of utilization. Paradoxically, the hardwoods themselves are one of the last frontiers of wood supply standing ready to help meet the ever expanding requirements of the wood-using industries, particularly the pulp and paper industry. Fortunately, the hardwoods have recently been recognized as desirable contributors to the economy of the forests. For example, the formerly ill-regarded aspen is now being cultivated in the Lake States, and appreciable quantities of the generally unesteemed oaks are being used by pulp mills in the Appalachian area. In fact, there has been a phenomenal increase in hardwood pulpwood consumption in recent years (fig. 1). Indeed, the hardwood pulp industry, using nearly 4 million cords, is a sizable industry in itself.

There are, of course, many other possibilities for hardwood utilization in addition to pulp and paper, such as certain lumber uses, containers, veneer and plywood, chemical utilization, and the like.

It is the purpose of this report to show that the pulp and paper industry offers valuable tools for utilizing hardwoods. The discussion will be illustrated by examples of recent research at the Forest Products Laboratory in this field.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

ABOUT THE AUTHOR: McGOVERN, JOHN N. Received BS, MS and PhD in chemical engineering from the University of Wisconsin, Madison, Wis. Joined staff of U. S. FPL in 1930 as a technologist, assumed present position in '46. Does research and development in all phases of chemical and semi-chemical pulping and utilization of domestic and foreign hardwoods, other little-used woods and fibrous materials and wood wastes in pulp and paper products.

Hardwood Pulps and Papers

Any hardwood can be pulped by one or more of the standard pulping processes to produce a pulp suitable for use in some paper product. Some hardwoods respond well to all the processes, and their pulps have a wide range of possible uses. Others give pulps of little value when made by certain of the processes. In any case, most hardwood pulp can probably best be utilized in a blend with long-fibered softwood pulps.

To make useful pulps from the hardwoods, it has generally been necessary to remove the bark. This has often been a difficult problem and has almost eliminated the hardwoods from consideration for pulp manufacture. However, there have been several interesting developments of late that promise to remove this important obstacle. These developments include chemical debarking, improved mechanical debarkers, methods for removing bark from mixtures of chips and bark, and methods for separating bark particles from the pulp after the pulping operation.

The present application of the commercial pulping processes to the hardwoods is discussed in the remainder of the report.

Semichemical and Coarse Fiber Processes and Products

Among the several processes used for hardwood pulping, the most outstanding at present are perhaps those using the high yield principle, namely, the semichemical and coarse fiber methods. These methods together consume about 26 percent of the hardwoods entering the pulp and paper industry, and their production is increasing.

Semichemical: Of special interest in the high yield field is the semichemical process, which has had a spectacular growth in the past 10 years as shown by the chart of productive capacity since it was first used in 1925 (fig. 2). In this method of pulping, wood chips are softened by partial cooking, then disintegrated in a disk refiner. The treating chemical can be any of the common pulping reagents, but sodium sulfite buffered to near neutrality with sodium carbonate or bicarbonate is usually used. The yield of pulp from this process is high—65 to 90 percent, depending on the wood and the use requirements of the pulp. This high yield is of tremendous importance in these days of

high wood costs. Another feature of the semichemical process is that it is particularly adapted to the hardwoods, which are generally dense woods giving a high weight of chips per cord.

Semichemical hardwood pulps were first used as the corrugated medium in container board. Straw had usually been used for this purpose, but semichemical board made from hardwood is now the standard for this commodity. Semichemical pulps have also been used in other types of boards, as well as in small amounts in newsprint. The fact that the semichemical pulps can be readily bleached with standard procedures and equipment to make a product satisfactory for replacing bleached chemical pulp in some kinds of paper has greatly expanded the possible uses of hardwoods. Bleached semichemical hardwood pulp has many of the qualities of softwood sulfite pulps and therefore has its multitude of uses. This branch of the industry has grown in the past few years, and bleached hardwood semichemical pulps are now used in book and other printing papers, bond and other fine papers, greaseproof and glassine papers, and food boards of various types.

The semichemical pulping process was used at the Forest Products Laboratory in an investigation of the use of an eastern hardwood mixture in high-grade bond paper (*2*).[2] In this study a semichemical pulp was made in a yield of 70 percent from a mixture of nine hardwoods (table 1). The pulping required 19 percent of sodium sulfite and 5 percent of sodium bicarbonate based on the moisture-free weight of the wood charged to the digester. The time at the cooking temperature of 170° C. was 3 hours. The partially cooked chips were fiberized to a pulp in a disk refiner that required 16 horsepower-days per ton of air-dry pulp. The optimum degree of fiberizing with respect to bleachability and the presence of shives or fiber bundles was at a freeness level of about 700 milliliters (Schopper-Riegler). The pulp contained an appreciable amount of wood dirt and short shives that were successfully removed by a centrifugal separation treatment. The pulp was bleached to a brightness of 84 percent using a three-stage procedure comprising chlorination, caustic extraction, and hypochlorite bleaching. The total chlorine used was 13.5 percent, based on the weight of the unbleached pulp. The yield of bleached pulp was 55 percent, based on the weight of the wood at the start.

The quality of this bleached hardwood semichemical pulp was judged by comparing it with a strong, bond-grade, bleached sulfite pulp made commercially from spruce. The hardwood pulp closely approached the softwood pulp in bursting strength, had a somewhat higher tearing resistance, but was somewhat lower in tensile strength and appreciably lower in folding endurance (table 1). The hardwood semichemical pulp was strong enough to be considered seriously as a substitute for or supplement to the softwood sulfite pulp in high-grade bond paper.

Bond paper made on the Laboratory's 12-inch Fourdrinier paper machine from the hardwood semichemical pulp had strength properties equal to or better than a paper made from a commercial pulp furnish used in the manufacture of high-grade bond paper (table 1). The semichemical paper was lower in opacity than the standard, but this may have been due partly to the lower amount of filler present in the semichemical paper. The amount and visibility of the shives and other foreign particles in the semichemical paper was probably higher than could be tolerated in a No. 1 grade of bond paper, but considerable improvement could be expected by application of suitable cleaning measures, such as centrifugal separation, in addition to that applied to the unbleached pulp. At any rate, it should be possible to use at least 25 percent, and probably higher percentages, of bleached hardwood semichemical pulp in bond and similar papers of the highest quality.

Cold Soda: A variation of semichemical pulping, which entails steeping wood chips in a sodium hydroxide solution in the absence of heat or pressure followed by mechanical fiberization, is a newly developed tool for utilizing hardwoods. This method, called the cold soda process, has had a small commercial application in the short time since its origination, and is believed to have considerable promise for expansion in the future. The method can be applied to a wide variety of hardwoods growing in the United States. The features of the process are the very high yields of pulp—85 to 95 percent of the original wood—and the simplicity of the operation. The cold soda pulps generally occupy a position between neutral sulfite semichemical pulps and groundwood pulps in their properties. The cold soda pulps have been used commercially in the manufacture of corrugating board, but there appears to be wider use possibilities than this, such as in printing papers of the groundwood type. This is of particular interest because groundwood pulps from the dense hardwoods are generally too weak for extensive use in these papers.

Experiments at the Laboratory show that this process can be used in the production of a newsprint containing appreciable quantities of hardwood pulp (*1*). A cold soda pulp was prepared from aspen (*Populus tremuloides*) by steeping chips for 2 hours in a sodium hydroxide solution of 45

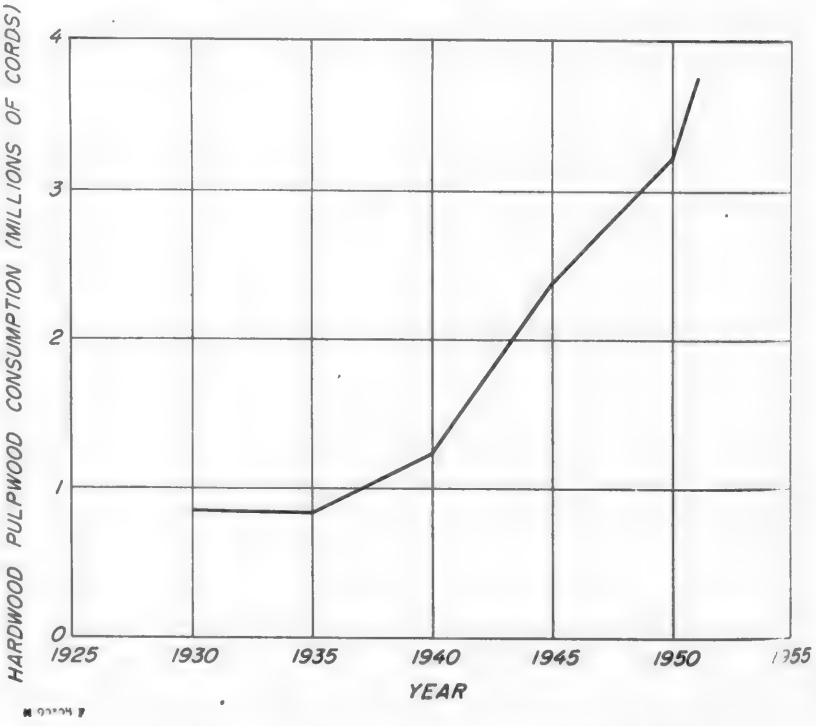

Figure 1.—Hardwood pulpwood consumption has increased rapidly in recent years.

[2] Italic numbers in parentheses refer to Literature Cited at the end of this report.

grams per liter concentration at room temperature (28° C.). The treated chips were then fiberized to a pulp in a disk refiner with an expenditure of 28 horsepower-days per ton of air-dry pulp. The freeness of the pulp was 415 milliliters (Canadian Standard) and the yield, based on the weight of wood charged, was 88 percent. The pulp was brightened from 49 to 70 percent by applying calcium hypochlorite in an amount equivalent to 10 percent of the weight of the unbleached pulp. This pulp was made into a sheet of news weight, and was also used in the amount of 20 percent together with commercial spruce groundwood and sulfite pulps. For comparison, a standard newsprint paper was made from 20 percent sulfite and 80 percent groundwood spruce pulps.

The high-yield cold soda pulp from the short-fibered aspen had a relatively high proportion of fibers retained on the coarse fractionation screen and a small percentage of fines (table 2). This pulp had good strength for its type, although the test sheets were fairly dense. The strength values were lower, however, than those commonly shown by neutral sulfite semichemical pulps.

In comparison with spruce groundwood pulp of newsprint grade, the aspen pulp had a considerably higher freeness value and fiber length index, was much stronger and appreciably denser (table 2). The test sheets from the cold soda pulp were also stiffer and more transparent than those from the groundwood pulps. The somewhat high density is characteristic of cold soda pulps, although to a less extent than of semichemical pulps. However, this characteristic can be controlled to some extent by the amount of fiber processing in the fiberizing of the treated chips.

The news-weight sheet made from 100 percent aspen cold soda pulp was strong in comparison with standard newsprint, but the sheet tended to be stiff and was low in opacity (table 3). In other words, it lacked some of the important properties of a paper for printing. However, when a pulp furnish containing 20 percent of the cold soda pulp as a partial substitute for both groundwood and sulfite pulps from spruce was used, the sheet of paper was satisfactory in all respects (table 3). Thus a hardwood pulp can be used in newsprint and in other printing papers. Experiments with other hardwoods—red alder and sweetgum—have shown even more promising results than those described for aspen.

Hardboard: The wallboard or structural board class of coarse fiber products—hardboards, insulating, and sheathing boards—now consumes appreciable quantities of hardwoods and probably will use even more in the future. This branch of the pulp and paper industry has been shown in commercial practice to be a fitting tool for the utilization of hardwoods.

In one investigation at the Laboratory, several eastern hardwoods were shown to be suitable for the production of Class A hardboards (*3*). Standard chips from beech (*Fagus grandifolia*), birch (*Betula* sp.), and *hard and soft maples* (*Acer* sp.) were fiberized individually in a laboratory-model Asplund Defibrator after presteaming for 3 minutes at 175 pounds per square inch pressure and milling for 2 minutes at this pressure. The yields of fiberized pulp from the beech and maples were in the range of 84 to 86 percent and those from the birch were 81 to 82 percent. Some of the pulp was refined in a Valley test beater, and nominal 1/8-inch hardboards were made from both unrefined and refined stocks. Both sized and unsized mats were formed in a Defibrator freeness tester. Both paraffin and rosin were used for sizing and were affixed by adding alum and sulfuric acid to a pH value of 4 to 4.5. The mats were cold-pressed to remove excess water and then hot-pressed at temperatures ranging from 180° to 240° C. with a maximum pressure of 500 pounds per square inch. The boards were tested for water absorption and static bending strength for comparison with the specifications for Class A board, which are: maximum water absorption of 20 percent and minimum modulus of rupture of 6,000 pounds per square inch.

The refined, unsized stocks gave strong boards that met the Class A specifications for strength with a moderate pressing temperature of 180° C. Pressing at 240° C. gave exceptionally high strengths—in the range of 8,000 to 9,000 pounds per square inch. These boards probably would have many applications, although they did not meet the Class A specifications for water resistance.

The following results were obtained in the sized boards: (1) Maple, birch, and beech stocks sized with 2 percent

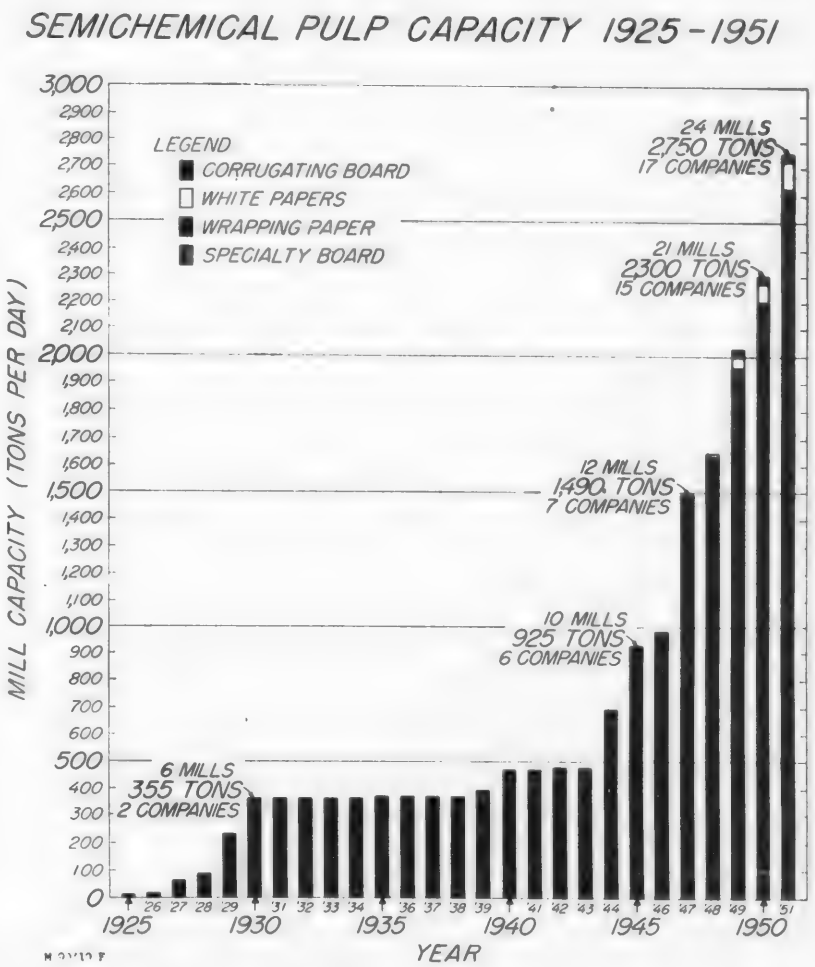

Figure 2.—The semichemical process has shown spectacular growth since it was first used in 1925.

of paraffin and 4 percent of alum and molded at 240° C. produced Class A hardboards; (2) soft maple hardboard sized with paraffin and molded at 195° C. also met Class A standards; and (3) boards sized with rosin and ferric sulfate and molded at 195° C. were stronger and more water resistant than comparable boards sized with paraffin and alum. However, only the soft and hard maple hardboards of the last group were of the Class A grade. Results are given in table 4.

Saturating Felts: The saturating class of coarse fiber products includes roofing, flooring, deadening, and insulation products. Formerly made almost entirely from rags, these products tend to have an increasing proportion of wood fibers in their makeup. Hardwood fibers serve well and are widely used for this purpose. Apparently the top quality and best form of wood are not required. Thus the saturating felt products with their content of coarse fibers, usually produced by the Asplund process, offer another useful tool for hardwood utilization.

Groundwood Process

The groundwood process consumes about 18 percent of the hardwoods used by the pulp industry. The lightweight hardwoods like aspen and cottonwood make good quality groundwood pulps having many of the uses of softwood groundwood pulps, such as in newsprint and printing papers. On the other hand, the dense hardwoods, like sweetgum, birch, maple and beech, and the oaks, which are found in considerably greater quantities than the lightweight woods, make poorer groundwood pulps by accepted standards when ground according to present commercial practices. However, experiments show that these pulps can be used in quantities up to about 30 percent in printing papers, toweling, and other specialties. They blend well with neutral sulfite and cold soda pulps, acting as a filler and a softening constituent.

Experiments at New York State College of Forestry and elsewhere have shown that more serviceable pulps can be produced from hardwoods by chemical treatment of wood bolts under pressure and moderate temperature followed by conventional grinding. The degree of chemical treatment influences the amount of improvement in strength and other characteristics. However, improved strength and lower energy consumption is generally accompanied by increase in density and loss of some of the properties for which groundwood is noted, namely, bulk, softness, and opacity.

Table 1.--Properties of hardwood semichemical and softwood sulfite pulps and bond papers made from them

Item and properties	Type of pulp	
	Hardwood semichemical[1]	Softwood sulfite[2]
Pulp test sheet:[3]		
Bursting strength.....pts. per lb.	0.93	1.02
Tearing resistance.....gm. per lb.	1.13	.98
Folding endurance.....double folds	222	950
Density.....gm. per cc.	.74	.....
Bond paper:[4]		
Bursting strength.....pts. per lb.	.74	.46
Tearing resistance.....gm. per lb.	1.03	.96
Folding endurance.....double folds	130	62
Opacity.....percent	79	86
Ash.....percent	5	7
Density.....gm. per cc.	.78	.83

[1] Mixture of nine eastern hardwoods including black cherry (Prunus serotina), sugar maple (Acer saccharum), red maple (A. rubrum), yellow birch (Betula alleghaniensis), sweet birch (B. lenta), beech (Fagus grandifolia), white oak (Quercus alba), red oak (Q. borealis), and white ash (Fraxinus americana).

[2] Spruce (Picea sp.).

[3] Ream of 500 sheets, 25 x 40 inches.

[4] 52-pound sheet, same ream size as in footnote 3.

Table 2.--Properties of aspen cold soda and spruce groundwood pulps

Pulp properties	Type of pulp	
	Aspen cold soda	Spruce groundwood
Unbleached pulp:		
Freeness (Canadian Standard).....ml.	415	165
Screen analysis		
Retained on 24-mesh screen.....percent	18.2	15.4
Passing 150-mesh screen.....percent	21.1	34.6
Fiber length index.....	.162	.112
Unbleached pulp test sheet:[1]		
Bursting strength.....pts. per lb.	.44	.25
Tearing resistance.....gm. per lb.	1.16	.63
Breaking length.....m.	4,000	2,700
Density.....gm. per cc.	.58	.43

[1] Ream of 500 sheets, 25 x 40 inches.

An investigation at the Forest Products Laboratory by Hyttinen and Schafer showed this modified groundwood method to be a promising approach to the problem of making useful pulps from the hardwoods. Sweetgum (*Liquidambar styraciflua*) was made into a groundwood pulp from untreated bolts and bolts that had been pretreated by impregnation and cooking in a solution of sodium sulfite and bicarbonate at a temperature of 145° C. for 5.5 hours (table 5). The untreated wood gave a typically weak, dark-colored groundwood pulp having a very low proportion of long fibers and a high proportion of fines. The pulp from the treated wood, on the other hand, was high in freeness, strength, and proportion of fiber retained on coarse screens. The energy consumed in making the pulp from the treated wood was low—32 horsepower-days per ton—and the grinding rate was high. The yield of treated fiber was estimated to be between 85 and 90 percent of the original wood. The brightness of the pulp from the treated wood, about 51 percent, was appreciably higher than that of the normal sweetgum groundwood, but brightening would still be necessary for most uses. The density of test sheets of chemigroundwood pulp fell in the range of that for spruce groundwood pulps. The sweetgum chemigroundwood was higher in strength and freeness than spruce groundwood pulp used in printing paper, and approached semichemical pulp from the same species in many strength properties. Its properties indicated it could be used for most products containing groundwood and also as a part substitute for chemical pulp, such as certain sulfite pulps.

Sulfate Process and Products

Although the sulfate pulping industry used only about 13 percent of the total hardwoods consumed for pulp and paper in 1951, it is a growing industry. The expansion plans for many large companies rely heavily on hardwoods to supply an important proportion of their future pulpwood requirements. The sulfate process can be used on all United States hardwoods, although there is a range of pulp quality depending on wood species. The top quality hardwood sulfate pulps have properties that compare favorably with softwood sulfite pulps in most respects and have many of the same uses. Because of the higher strength of sulfate pulps, there has been a trend toward using them to replace hardwood soda pulps. The hardwood sulfate pulps should have use in most products where the highest strength is not paramount. As a

Table 3.--Properties of some newsprint papers made from aspen cold soda, spruce groundwood, and spruce sulfite pulps

Newsprint paper properties[1]	Type of pulp		
	Aspen cold soda[2]	Spruce groundwood-sulfite[3]	Hardwood softwood[4]
Density.....gm. per cc.	.89	.67	.77
Bursting strength			
Mullen.....pts.	10.2	5.9	6.3
Unit.....pts. per lb.	.28	.17	.18
Tearing resistance.....gm. per lb.	.64	.58	.59
Tensile strength.....lb. per in. width	10.4	6.7	6.5
Oil penetration.....sec.	58	51	53
Porosity.....sec.	58	28	45
Opacity.....percent	76	88	89
Brightness.....percent	70	60	62

[1] 30-pound sheet; ream of 500 sheets, 25 x 40 inches.

[2] 100 percent of bleached cold soda pulp described in table 2.

[3] 80 percent of spruce groundwood pulp described in table 2 and 20 percent of spruce sulfite pulp.

[4] 70 percent of spruce groundwood, 20 percent of aspen cold soda, and 10 percent of spruce sulfite pulp. Groundwood and cold soda pulps are described in table 2.

Table 4.—Properties of nominal 1/8-inch hardboards from eastern hardwoods compared with specifications for Class A boards

Type of hardboard	Freeness (Defibrator)	Molding temperature[1]	Board data			
			Specific gravity	Modulus of rupture	24-hour water immersion	
					Water absorption	Thickness change
	Sec.	°C.		P.s.i.	Percent	Percent
Beech	46	240	1.02	6,100	18.6	12.7
Birch	39	240	1.05	6,300	18.2	12.0
Soft maple	43	195	1.05	6,200	17.1	16.3
Hard maple	40	240	1.05	7,600	17.0	12.7
Class A[2]	.....	.....	[3].96	[4]6,000	[3]20.0	.....

[1] Sizing and molding conditions: Stocks sized at a consistence of 2 percent. Sized with 2 percent paraffin and 4 percent alum; dilute sulfuric acid added to slurry to bring pH value to 4.0 to 4.5. Boards molded with maximum pressure of 500 pounds per square inch.

[2] Federal Specification LLL-F-311, Amendment 3, 1952.

[3] Minimum allowable value.

[4] Maximum allowable value.

matter of fact, hardwood sulfate pulps are being used in a great variety of papers in the publication, writing, printing, and absorbent paper fields. In addition, a special grade of hardwood sulfate pulp has come into being in recent years—a highly purified pulp to be dissolved or modified to form cellulose derivatives such as rayon. All these means of utilizing the hardwoods through the sulfate process may be expected to increase hardwood use.

The Forest Products Laboratory has been active in the sulfate pulping industry. For example, the Laboratory has investigated the application of the prehydrolysis-sulfate process to aspen to produce a pulp for conversion to cellulose acetate (*4*).

Because the hardwoods are inherently high in the hemicellulosic fraction of pentosans, which are incompletely dissolved by the sulfate cooking reagent and are highly detrimental to the quality of pulps for chemical conversion, it is generally necessary to modify the conventional method of pulping. These undesirable pentosans can be removed by acid hydrolysis prior to the regular sulfate pulping operation. At the Laboratory, the hydrolysis was carried out by digesting the wood chips in water at a temperature of 170° C. for 0.5 hour. At this high temperature the water reacts with the wood to form acetic acid, which furnishes the acid needed to dissolve the pentosans. The pH value at the end of the hydrolysis treatment was thus 3.8, or fairly strong on the acid side. The hydrolyzed chips were then pulped conventionally by the sulfate process. The yield of pulp under these conditions was 42 percent of the original charge. Further, this pulp had a low pentosan content of 2.8 percent and a satisfactory viscosity value of 37.6 centipoises when tested in cuprietheylenediamine in 0.5 percent concentration. The pulp had other characteristics indicating its suitability for the purpose intended.

The unbleached sulfate pulp was purified by a procedure involving chlorination, hot or cold alkaline extraction, and treatment with sodium hypochlorite and chlorine dioxide. The hot extraction was made with 5 percent sodium hydroxide by weight applied at 0.6 percent concentration at 70° C. for 1 hour; the cold extraction was made with a caustic soda solution of 5 percent concentration of 250° C. for 1 hour. The yield of pulp purified by cold alkaline extraction was 38.2 percent based on the original wood charge and the pulp had an alpha cellulose content of 97.3 percent, a pentosan content of 2 percent, and a viscosity of 18.4 centipoises.

Table 5.--Results of grinding treated and untreated sweetgum

Item	Untreated	Treated
Treating conditions:		
Concentration of treating solution[1]....gm. per l.	.....	120
Temperature....°C.	.....	145
Time....hr.	.....	5.5
Pressure....lb. per sq. in.	.....	150
Grinding conditions[2] and results:		
Pressure....lb. per sq. in.	25	25
Rate of grinding....		
....tons per sq. ft. of grinding surface per day[3]	1.4	1.9
Energy consumed....horsepower-days per ton[3]	60	32
Pulp properties:		
Freeness (Schopper-Riegler)....ml.	290	660
Screen analysis:		
Retained on 24-mesh screen....percent	.5	44.7
Passing 150-mesh screen....percent	58.9	34.4
Fiber length index....	.074	.128
Test sheet properties:		
Bursting strength....pts. per lb.[4]	.08	.40
Tearing resistance....gm. per lb.[4]	.31	.96
Breaking length....m.	910	3,680
Density....gm. per cc.	.34	.41
Brightness....percent	45	51

[1] Sodium sulfite and sodium bicarbonate in ratio of 6:1.

[2] 10-cut, 1-1/2-inch lead spiral burr pattern; stone surface condition, dull.

[3] Moisture-free wood basis.

[4] Ream of 500 sheets, 25 x 40 inches.

The pulp purified with hot alkaline extraction and treatment with sodium hypochlorite was made in a yield of 37.6 percent and had an alpha cellulose content of 94.7 and a pentosan content of 2.2 percent with a viscosity of 12.5 centipoises. Finally, the pulp purified with hot alkaline extraction and treatment with chlorine dioxide was made in a yield of 37.7 percent and had an alpha cellulose content of 95.5 and a pentosan content of 2.5 percent with a viscosity of 16.3 centipoises. The two pulps purified by hot alkaline extraction were acetylated at an industrial laboratory, and the cellulose acetate made into yarn. The acetylation operation was reported to be conducted satisfactorily, and the yarns were as strong as yarn made from commercial softwood sulfite pulp of acetylation grade. The pulp made with cold extraction did not acetylate satisfactorily.

Soda Process and Products

The soda process is particularly applicable to the hardwoods for producing soft, opaque, bulky pulps ideally suited for use in book and magazine papers. Roughly 25 percent of the present hardwood pulpwood consumption is by the soda process, but the percentage will probably decrease as other processes increase their production. The production of soda pulp has been slowly declining, mostly because of the relative weakness of the pulp and its limited usefulness. Soda pulps or modified soda pulps will continue to be made because of their special properties, but an expansion in their use is not expected. Nevertheless, this process is still a valuable tool for utilizing substantial amounts of hard woods.

Sulfite Process and Products

The sulfite process is also a useful tool for hardwood utilization, although it perhaps has a less promising future than some of the others. This process consumes about 18 percent of th total amount of hardwood used for pulp at the present time. The manufacture of hardwood sulfite pulps i limited to mills in the Lake States an the Northeast because sulfite mills a located only in these areas. The sulfit process can be applied to most of the hardwoods, although there are a few exceptions—cherry, for example. The

pulps range from low to good in strength, depending on species, and have a fair number of uses, including printing, bond, and tissue papers, and purified pulp used mostly for making cellophane. In spite of the several useful properties of the hardwood sulfite pulps, they are not likely to show an increase in production because of their limitations and the apparently limited future expansion of the sulfite process as a whole. However, as with the soda process, the sulfite process will continue to serve as a valuable tool for hardwood utilization.

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Discussion

Dr. Samuel A. Woodruff (Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio): 1. May conventional pulping equipment be used to prepare semi-chemical pulp? 2. What pulping process could best be modified to be a continuous process?

Mr. McGovern: 1. Conventional equipment can be modified and adapted to prepare semi-chemical pulp. Both rotary and vertical digesters have been adapted from sulfate to semi-chemical pulping. 2. Attempts are being made to develop continuous pulping processes to reduce labor costs and to obtain better control in shorter cooking times. Attempts are being made to put all pulping methods on a continuous process with most success being obtained in the alkaline and high yield processes.

Reavis C. Sproull (Herty Foundation, Savannah, Ga.): Can we expect to balance pulping processes of hardwoods and softwoods according to the growth of the species and if so, how long will it take?

Mr. McGovern: We will probably never balance the proportion of hardwood and softwood pulp according to growth since use requirements dictate the use of the longer softwood fibers if they are available. We will develop new methods and use more hardwoods as the competition for the softwoods increases.

Norman F. Smith (Michigan Department of Conservation, Lansing, Michigan): Since these so called "weed species", such as aspen, white birch, soft maple, and oak, are fast growing trees, and are bringing our growth and utilization into balance, and also since many companies are going to considerable expense to convert to their use and are interested in long term supplies, is not the problem one of reproducing and managing certain of these species rather than converting to other types?

Mr. McGovern: We feel that the same effort might be devoted to grow better trees rather than perpetuate the less desirable ones. Since this is more of a forestry question, I would like to refer it to Walton Smith.

Walton R. Smith (S. E. Forest Exp. Sta., Asheville, North Carolina): The problem varies by species and by areas. I could agree with Mr. Norman Smith that in the case of aspen and some other species we should devote more research to its management and perhaps perpetuation, but when it comes to scrub oaks in the South, there are many species that will better serve our needs.

Elmer E. Matson (Pac. N. W. For. Exp. Station, Portland, Oregon): The determination of the species to perpetuate depends a great deal on the particular site. In some cases, the so-called "weed species" may be the best species in the long run. In the Pacific Northwest, upland alder is a so-called weed species. On these sites we can grow twice as much Douglas fir as alder. Therefore we should try to convert to fir. On good sites alder makes good growth and should be perpetutated. In Michigan, you have a similar problem. Much more Jack Pine can be grown on the sand plains than aspen, while on good hardwood sites aspen makes good growth.

The Outlook For the Utilization of Mesquite

E. D. Marshall
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Mesquite (*Prosopis* spp.) has invaded extensive areas of range lands in the Southwest. Various successful methods of mechanical and chemical eradication have been developed. Utilization research, however, has lagged behind. With the limited knowledge at hand, it appears that charcoal and flooring blocks made from mesquite offer commercial opportunities. By grinding the entire tree and combining with a cheap binder, a hardboard suitable for interior use may be made.

Introduction

THE NUMBER ONE PROBLEM of range management in the Southwest is somewhat similar to the number one problem of forest management in the South in that both are concerned with the elimination and utilization of inferior hardwoods. However, in the South the principal species involved are oak and gum; in the Southwest, the principal species involved is mesquite. Although there is considerable information available on the utilization of southern hardwoods, this information, except in very general terms, is not directly applicable to mesquite utilization. The physical and chemical properties of mesquite and the economic considerations related to mesquite utilization are sufficiently divergent from those of southern hardwoods and of the South to justify this separate treatise on mesquite utilization. Mesquite is unique only to the Southwest and is as characteristic of the area as rattlesnakes, northers, cornbread and tortillas.

Mesquite (*Prosopis* spp.) is a leguminous hardwood. The twigs are armed with straight hard spines up to 1½ inches in length. Fleshy seed pods or "beans" up to eight inches long occur on the tree from May to September.

Exact identification of species or variety within the genus *Prosopis* is often difficult. Furthermore, botanists are not in full agreement with regard to the taxonomy of the species. In this paper, most mesquites in the Southwest will be considered as comprising one species, *Prosopis juliflora* (Swartz) de Candolle. Three varieties of this species are recognized: "honey mesquite" common in Texas; "western honey mesquite" common in the extreme part of western Texas, in southern New Mexico, and in southeastern Arizona; and "velvet mesquite" common in Arizona. The size, shape, and hairiness of the leaflets is the main basis for distinguishing these varieties. A less prevalent species, tornillo or screwbean (*Prosopis odorata* Tore and Frem.), is easily distinguished by its tightly coiled seed pods and is usually confined to valley bottoms where it may form heavy thickets.

To the layman most mesquites in the Southwest appear alike except for differences in size and growth forms. Three types of growth are recognized for the purpose of this discussion: (1) trees up to two feet in diameter and fifty feet in height, (2) many-stemmed shrubs one to three feet in height, and (3) a scraggy woodland type with one or more main stems and intermediate in stature between the small shrub and tree forms. The larger tree-size mesquite occurs in river bottoms. The intermediate forms occur on upland areas of compact soil and moderate moisture. The many-stemmed shrub three feet or less in height occurs mainly on semi-arid or windswept localities with sandy or caliche soil. Although this latter type is a serious range pest, the tree and intermediate shrub forms of mesquite cover by far the greater area in the Southwest and affect the largest segment of the livestock industry. (See Fig. 1) The distribution of these forms, which is of primary interest in considering utilization potentials, is shown by the heavily hatched (major distribution) area on Fig. 2. The greatest area and volume of these larger growth forms occur in Texas. Although land clearing operations such as shown in Fig. 3 have eradicated mesquite from a portion of this area of major distribution, nevertheless, there are large areas remaining in the Southwest with two or more cords of mesquite per acre.

Physical and Chemical Properties

The heartwood of mesquite is reddish-brown and the sapwood is yellowish-white. The sapwood band is narrow regardless of diameter or site.

The specific gravity of the wood averages around 0.70. The wood is hard, brittle and cross-grained. It lacks bending strength and toughness. It finishes well in machining and its gluing properties are satisfactory.

The mean moisture content of freshly-cut wood grown in Texas ranges from 55 to 75 percent. Upon drying the wood exhibits unusually low shrinkage values: tangential, 2.6%; radial, 2.2%; and volumetric, 4.7%. Based upon limited experience, the drying characteristics of 4/4 mesquite are satisfactory when seasoned on kiln schedules similar to those used on 4/4 southern oak. When properly air-dried or kiln-dried, very few seasoning defects appear in the wood. Shake often occurs through the center of the main stem of mesquite trees. (Fig. 4).

The bark is thin and difficult to remove. An ordinary pine pulpwood debarking drum does not remove the bark satisfactorily. The bark is of high density and averages around 20 percent moisture content..

The mean of four separate chemical analyses of mesquite wood is given in Table 1.

The water solubles are relatively high and probably consist mainly of gum, tannic acid and carbohydrates. The wood has a rather high ether soluble content for a hardwood. The alkali soluble extract (consisting primarily of tannins, resin acids, and carbohydrates) is also rather high. The cellulose content of the wood is relatively low; the lignin content is around the average of other woods.

Mesquite gum exudes as white or amber-colored droplets from the bark

Figure 1.—Intermediate growth forms of mesquite. Crown density ranges up to impenetrable thickets. Such small volumes per acre as shown above are considered to be near the lower limit with respect to any commercial utilization possibilities.

Table 1—CHEMICAL ANALYSIS OF MESQUITE WOOD

Item	Percent of weight of oven-dry samples	Percent of total cellulose
Moisture	5.49	
Ash	0.54	
Solubility in		
Cold water	12.62	
Hot water	15.09	
Ether	2.30	
1% NaOH	28.52	
Acetic acid	2.03	
Methoxyl	5.55	
Pentosans	14.73	
Lignin	30.47	
Cellulose	45.48	
Pentosans in cellulose		18.55
Alpha cellulose		76.48

Chemically, it is the inorganic salt of an organic acid consisting of four molecules of l–arabinose, three molecules of d–galactose, and one molecule of methoxyglucuronic acid united with the loss of seven molecules of water. It is believed that the gum canals in mesquite wood are lysigenous in origin.

An analysis of the tannin extractive from the wood, bark and leaves of mesquite is shown in Table 2.

Past Uses

Past utility of the wood has been largely for fuelwood and fence posts and restricted more or less to areas where mesquite stems were of sufficient size for such uses. The roots of certain growth forms in arid regions are oftentimes quite extensive and have been used for fuelwood.

Primary factors working to the disadvantage of mesquite for fence posts are its crooked form, difficulty in cutting and its relatively heavy weight as a post. Mesquite posts when cut during certain months in the winter or when soaked in alkali ponds are not so susceptible to attack by borers, the principal cause of deterioration. The heartwood is quite resistant to fungi and termites. Records indicate that mesquite posts may be serviceable for forty years or more within the mesquite range. If wire rather than staples are employed to fasten the fencing to the post, less fence repair will be needed when the sapwood band deteriorates and borers infest the posts. Today, relatively few mesquite trees are utilized for fence posts in Texas. Mountain cedar is used almost exclusively for fence posts within the mesquite areas in Texas.

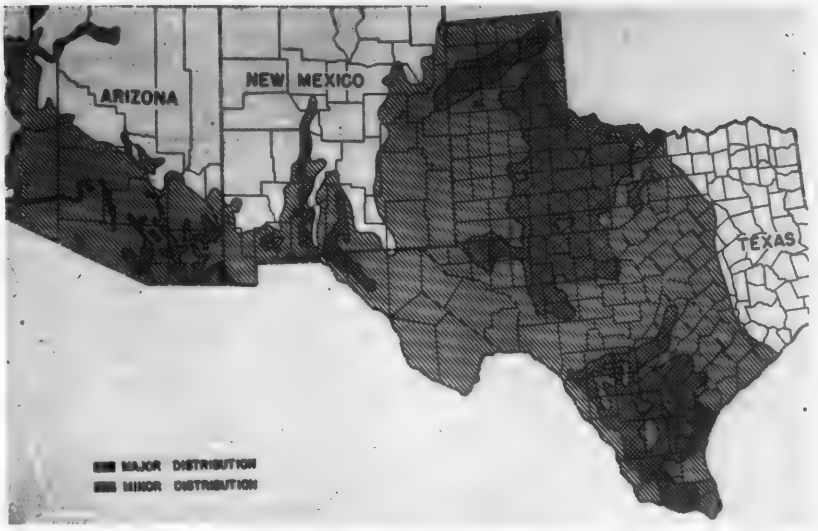

Figure 2.—Distribution of mesquites in Texas, New Mexico, and Arizona.

Mesquite, because of its high heat value, has been termed "wooden anthracite". The wood burns slowly and evenly and "holds the heat" well. The wood, however, is deleterious to iron grates and necessitates frequent replacements. With the extension of natural gas, bottled gas, and electric facilities, the use of mesquite for fuelwood has declined to the point where relatively little such use is made of the wood today.

A limited amount of mesquite lumber has been manufactured and used primarily for furniture.

Mesquite charcoal produced by the open pit method in Mexico has been sold in the United States.

In passing, it is of interest to note the uses for parts of the tree, other than the wood. In some areas, the flowers are an important source of nectar for honeybees. The bean pods may serve as important sources of feed for cattle during periods of drought. The beans are used by the Mexicans for bread meal and in San Antonio today such meal may be obtained. The bean pods which contain sugars have been used by the Mexicans for the preparation of alcoholic concoctions. It has been reported that the leaves have served as a base material in preparing eye lotions and for use in connection with venereal disease, headaches, and bleaching agents in washing clothes. The bark has been used for cases of indigestion and diarrhea. The roots have been used for whips; the thorns for spurs and pins. Many of these uses were originated by the Indians and passed on to the Mexicans.

Potential Utilization

Inasmuch as the wood is available mainly in small sizes and is crooked and difficult to cut, it appears that the greatest potential use for the wood in large volumes lies in the field of chemical conversion rather than mechanical conversion, or the use of wood as wood. However, where local areas support tree-size mesquite, there is at least one promising development in the field of mechanical conversion, as will be discussed below.

Chemical Conversion

The production of charcoal in small low-cost retorts—such as the Connecticut type kiln—may hold some promise of commercial development for mesquite. In fact, some Connecticut kilns were recently installed in Arizona for the production of mesquite charcoal. This was an aftermath of a test run on mesquite charcoal completed several months ago in Connecticut type kiln near Conroe, Texas (Fig. 5). It is reported that current retail prices for mesquite charcoal near the Arizona kilns is 12 cents per pound in five- and ten-pound lots and that local demand for the coal is strong. Oak charcoal produced and sold in Texas retails around seven cents a pound in five-pound lots. There is reason to believe that mesquite charcoal produced and sold in Texas would command a price equal to or higher than that of oak char-

Table 2—TANNIN CONTENT OF MESQUITE

Item	Heartwood Collected		Wood Collected	Bark Collected		Leaves Collected
	Spur, Tex.	Beeville, Texas	College Sta., Tex.	Beeville, Texas	College Sta., Tex.	College Sta., Tex.
Soluble solids	13.6	17.00	13.46	11.50	15.75	35.97
Tannin	5.0	8.76	3.32	4.69	6.18	2.61
Non-tannin	8.6	8.24	10.14	6.81	9.57	33.36
Insoluble solids	2.1	1.24	-----	1.18	-----	-----
Total solids	15.7	18.24	-----	12.68	-----	-----
Purity on soluble solids basis	36.6	51.5	24.7	40.7	39.2	7.26

Figure 3.—Bulldozer with extended push bar is but one of several types of mechanical equipment developed for use in the eradication of mesquite. Killing mesquite by spraying chemicals from airplanes as well as the use of kerosene and other compounds through ground operations is also practiced. Depending upon the density of the growth and the eradication method employed, costs of eradication range from a few dollars to fifty dollars per acre.

coal. Retail demand for mesquite charcoal is primarily for use as fuel in charcoal grills or barbeque pits. The larger cities and resort areas in the Southwest will probably offer the best market for such charcoal.

Mesquite charcoal should also be suitable for use in steel manufacture.

The feasibility of establishing a chemical plant to recover the condensible gases for such products as acetic acid and methanol is extremely doubtful in view of the low cost of producing such products snythetically.

A cord of mesquite wood from Texas yields around 1000 pounds of charcoal; from Arizona, around 700 pounds of charcoal. Apparently the main reason for this difference in yield lies in the fact that the Arizona mesquite is more crooked and therefore a lower cubic foot content of wood is contained in a cord. As low as 50 cubic feet of wood per cord has been reported for Arizona mesquite.

Mesquite yields a good grade of charcoal and compares favorably to charcoal now on the market produced from other domestic species. Tests on mesquite charcoal including moisture content, total volatiles, fixed carbon, ash, specific gravity, and crushing strength applied parallel and perpendicular to the grain indicate that the values, except that of ash content, are well within the range of those found and considered satisfactory for commonly marketed domestic charcoals. The ash content on a basis of oven-dry charcoal averaged 5.70 percent for charcoal produced from Texas mesquite. The average ash content for charcoal commonly produced from domestic wood species ranges from 1.0 to 5.0 percent. This higher ash content of mesquite charcoal is not surprising in view of the fact that the mesquite wood itself normally contains above average ash content. This higher ash content would be more likely to degrade the coal with respect to actual carbon yields than to degrade the charcoal generally marketwise.

Tests conducted on mesquite charcoal for use in the manufacture of activated carbon indicated that the yield was only 24 percent (on a dry basis) at an activity level of 175 (molasses test). Loblolly pine sawdust charcoal by comparison yielded 41 percent. To attain this activity level (175), loblolly pine sawdust charcoal was processed in 41 minutes; mesquite charcoal was processed in 92 minutes. Considering time and yield, mesquite charcoal would only be one-fourth as good a raw material as loblolly pine sawdust charcoal. Thus mesquite charcoal would have to be available at a much lower price than that of loblolly pine sawdust charcoal before mesquite charcoal could be considered as a suitable raw material for the production of activated carbon. Such a price relationship appears unlikely within the near future.

Mesquite Ash

Ash collected from burned piles of brush in land clearing operations and containing principally mesquite have been analyzed to determine possible fertilizer value of the ash. The results of this analysis indicated that the ash is rather low in phosphoric acid and potassium oxide but high in calcium oxide. (See Table 3). Magnesium oxide amounted to 1.44 percent.

Table 3—ANALYSIS OF ASH FROM MESQUITE CLEARINGS

	Percent
Total phosphoric acid	0.62
Insoluble phosphoric acid	0.39
Available phosphoric acid	0.23
Potash as potassium oxide	4.86
Calcium oxide	28.78
Magnesium oxide	1.44

The ash might be used locally for soil and crop improvement. County agricultural agents should be able to assist in evaluating the ash for a given condition. It is doubtful that collection of the ash for sale as a commercial fertilizer would result in a profitable business.

Hydrolysis

The hydrolysis of mesquite wood for the production of ethyl alcohol or of wood molasses or yeast for cattle feed does not appear feasible at this time.

Mesquite wood contains a relatively low carbohydrate content (around 46%) and high inert material that absorbs some of the sugar and decreases

Figure 4.—Shake occurring in mesquite stems probably results from wind action on the large crowns characteristic of tree-size mesquite. The brittle wood, in turn, gives way to shake. For most uses of the wood brought about through mechanical conversion, such defect lowers the yield or value of the final product.

the yield. The yield of reducing sugar was 29.2 percent. The low fermentability (63%) of the sugar decreased the yield of alcohol. The yield of 95 percent alcohol was only 27.8 gallons per ton of wood. However, due to the greater density of mesquite wood, the yield of 95 percent alcohol per cubic foot of digester space was 1.95 pounds.

The inhibiting substances that delayed fermentation slowed the production of yeast but upon acclimatization the yeast grew readily on the sugar. The yield of yeast amounted to 40 percent of the sugar or around 12 percent of the weight of the wood.

Paper and Board Products

A fair quality hardboard was produced by grinding the whole tree (leaves, bark, wood, etc.) and binding together with a cheap binder by a semi-wet process (Fig. 6). This type of raw material is frequently bunched for burning in land clearing operations (Fig. 7). Portable chippers could be employed at the site. Additional tests and cost analyses are needed to determine commercial opportunities for such a product.

Data is not available concerning the possibilities of softboard and hardboard produced from mesquite wood alone. Data on semi-chemical and chemi-groundwood pulping of mesquite is also unavailable.

Limited tests were conducted on sulfate pulping merely because of the convenience of the facilities of a local pine sulfate mill. The mesquite chips were loaded into a perforated stainless steel basket and suspended six feet from the top of the digester. The digester was then loaded with the regular pine chips and a normal liquor charge. Yields of mesquite pulp cooked on a regular southern pine schedule by the sulfate process were only 26.8 percent compared to around 47 percent yield on southern pine. Although the mes-

Figure 5.—Charcoal resulting from a test run of one cord of green Texas mesquite and one cord of air-dry Arizona mesquite. Both coals were produced simultaneously in a Connecticut-type kiln near Conroe, Texas. During commercial operations, mesquite wood with such wide differences in moisture content should not be charred simultaneously in the same retort.

quite was probably not pulped at optimum conditions, the low yield was apparently not due to excessive degradation of the cellulose inasmuch as the permanganate number was 94. Instead of refining the mesquite pulp in the Noble and Wood laboratory type beater for one hour as is the usual procedure, the refining was stopped at 16 minutes because the metal roll contacted the metal bed plate. However, the values of freeness, points mullen, percent mullen, and grams tear 16 ply, for mesquite pulp were considerably below those of southern pine pulp at the end of fifteen minutes beating time. Examination on the blue glass indicated that: (1) the cooked mesquite pulp had a fiber length approximating that of pine groundwood and (2) there was an estimated 15 percent by weight of trashy rejects or nonpulped material. Mixtures of unbleached mesquite pulp and unbleached pine pulp did not appear to offer any advantages. The paper produced from the mixed pulps contained dark-colored spots. This was probably due to the tannin in the mesquite.

Tannin Extraction

As discussed above under "physical and chemical properties", the mesquite wood and bark contains tannin. The yield of tannin is probably too low to support commercial extraction of tannin alone. However, if tannin extraction could be combined with the use of tannin-spent chips for processing into some commercial product, then tannin extraction might become profitable for uses such as in oil drilling muds and tanning hides. Certainly there is a wealth of hides as well as oil drilling activities in the area supporting mesquite growth.

Mechanical Conversion

Flooring: The hardness and beauty combined with the relatively low shrinkage values of mesquite wood suggests its use as flooring.

Laminated flooring was successfully produced from a half a carload of mesquite lumber shipped from Texas to TVA's experimental continuous type flooring mill. The flooring is produced from thin strips by laminating the best grade and next best grade on the top and bottom respectively with the poorest grade cross-laminated in the center. In comparison with the commonly-used cull oak timber in the TVA area, mesquite resulted in less waste and was easier to saw and plane but more brittle than oak. The laminated mesquite flooring was bonded with a phenol-resorcinol glue at 150 p.s.i. pressure and a glue spread of 70

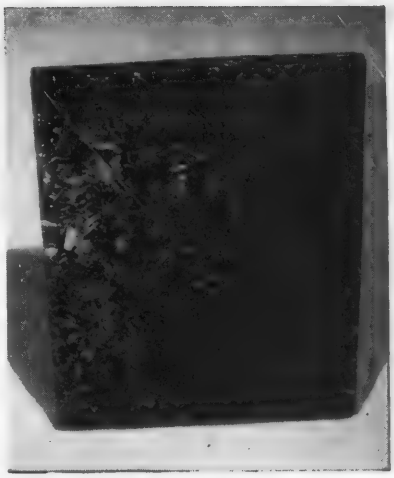

Figure 6.—Hardboard produced from mesquite branches—including leaves, thorns, pods, wood and bark. A cheap binder was used in a semi-wet process, resulting in a strong board at low cost and suitable for interior use.

pounds per thousand square feet of finished plank, a glue line temperature of 200° F., and a press time of two minutes. These were the same conditions used on laminated oak flooring. A few months ago I inspected some of these laminated mesquite planks used for flooring and wall panelling in a Texas home. After seven years of use, the material appeared to be in excellent condition. However, mesquite trees of sufficient size to produce sawlogs are not prevalent and for this reason we should not expect any great utilization trend toward such flooring or other products demanding lumber as raw material.

There is one type of flooring under development which appears to hold considerable promise because it utilizes mesquite trees of small diameter. The bolts are cut on a gang saw into cross-section wafers. After seasoning, the

(Continued on page 220)

Figure 7.—After bunching the mesquite in land clearing operations, it is common practice to burn the material. Here a man is filling a can with fuel oil preparatory to starting the fire. In contrast to this non-use or waste, a portable chipper could reduce this raw material to small pieces for the production of hardboard as shown in Figure 6—or the larger pieces could be selected for the production of charcoal as shown in Figure 5.

Figure 8.—Mesquite block flooring produced by cutting obliquely across small-diameter bolts is shown above. Polygon-shape pieces with equal length sides are produced by cutting at right angles across the larger-diameter bolts. Small areas of the yellow sapwood may be left on the corners for color effects. The disadvantage of the shake prevalent in most pieces might be overcome through clever salesmanship.

Wood in a Gulf Coast Chemical Plant

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The value of the preservative treatment for all wood is stressed. Examples of failures of untreated, improperly or poorly treated wood are included. Examples of wood as a replacement for steel are indicated. Quantities required for the annual maintenance program and the amount of timber used as piles and poles in a Gulf coast chemical plant are given.

The need for better preservatives for marine use is suggested and an urgent need for fire proofing wood is illustrated.

POPULAR-MAGAZINE articles dealing with the American chemical industry, appearing in numbers in recent years, have painted a fairly-well standardized picture of chemical plants. There are great steel towers, weirdly shaped, rising high into the skies. There are steel tanks—spherical, cylindrical, square, conical—grouped about the towers. Miles and miles of steel pipe lace these units together, and tie them into other units such as boilers, generators, reactors, pumps.

The picture is one of metals at work.

Yet, under and around and through that pattern of metallic structures, there is another pattern—made of wood. Wood, as experience in the Texas Division plants of The Dow Chemical Company has demonstrated, takes an integral part in chemical plant operations. There are many basic structures for which wood is the only practical material.

More important, trial has proved that the very nature of some chemical operations makes wood, not an *acceptable* but the *preferred* material for certain installations. Examples of this will be presented later. As a beginning, let us examine some facts about the Dow Texas Division plants and the use of wood there.

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The plant sites of the Texas Division of the Dow Chemical Company are in south eastern Brazoria County, near the mouth of the Brazos River and on the Gulf of Mexico. The region is a low coastal plain, and elevations of the plant sites range from 4 to 10 feet above sea level.

It is hard to determine whether location of sources of structural wood was considered in choosing this plant site; in all probability, this factor would have been given little weight in comparison to other, more primary, considerations. At any rate, the Texas Division now finds its nearest large source of wood as a structural material to be in the East Texas-Louisiana-Arkansas region—as shown in Figure 1.

From sources in the south comes the wood most widely used, by volume, in Dow's Texas Division plants This is the long- and short-leaf yellow pine, employed as common, yard, and select lumber for all structural purposes.

Fir ranks second to pine in volume of usage. Having somewhat greater durability than pine, (1) fir is principally used in piling, poles, and cross arms and, to a lesser extent, as structural lumber for buildings. But to secure fir, as Figure 1 shows, the Texas Division must go a considerable distance to obtain the finished timber needed.

Another distant source is that for finished redwood, as shown here in Figure 1. Volume needs for redwood are not too great, this material finding its principal use in cooling towers for handling waters in various processing plants. Other woods—oaks, gums, ashes—are used in relatively small quantities in cross and switch ties, pallets, dunnage, and similar forms.

Wood Requirements

All in all, the annual requirement for structural wood in the Texas Division has undergone a steady increase. Much of this increase stems from the

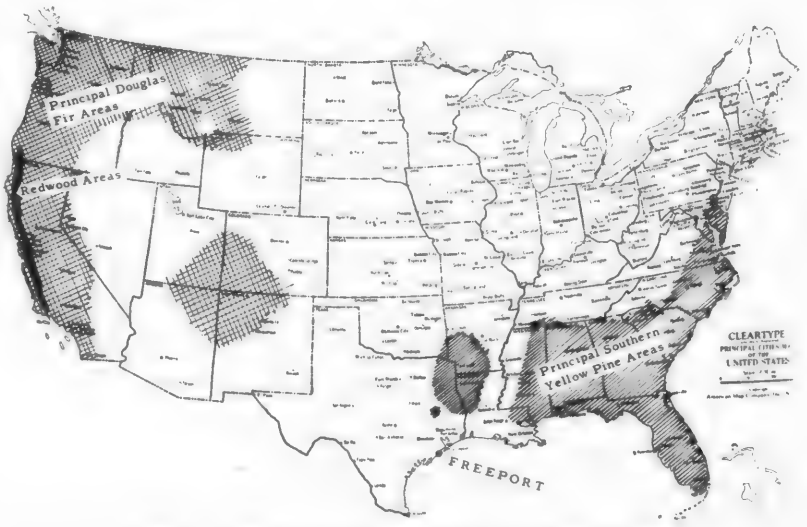

Figure 1.—Freeport and principal sources of structural lumber.

Figure 2.—Untreated window frame and sill decaying after seven years.

Figure 3.—Untreated rafters and framing decaying after six years.

Figure 4.—Comparing untreated wood framing with treated studs showing termite attack after five years.

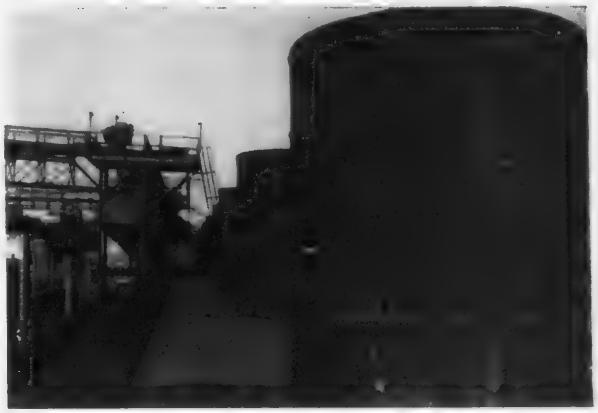

Figure 5.—Stacks impregnated with coal tar against chemical attack.

tremendous growth of the Dow Chemical Company plants in Texas since the first installation some thirteen years ago. Construction needs, of course, vary with the extent of construction programs. But a good indication of continuing wood requirements is offered by statistics on volume of wood used for maintenance; in the three-year period, 1950–1952, inclusive, a total of 1,861,936 board feet of lumber was required for maintenance alone; the average annual usage for upkeep purposes was about 620,600 board feet. These figures are lump sum totals covering all forms.

It may be well, however, to present some detail on one construction lumber item—a round stock, or poles and piles. As stated previously, these plant sites are only a few feet above sea level. And the need for piling is increased since, in the dredging of canals and rivers, much silt has been pumped onto the ground so that the soils are characterized by a low bearing capacity.

Piling is, therefore, widely used. It is current practice to divide all piling into two classes, according to different uses and different preservative treatments applied on basis of such use. In one class are grouped all piling used for inland structures—such as supports for tanks, equipments, and buildings. The second class covers piling used in salt water structures—for docks, bridges, wharves, and fenders.

The other principal uses of round stock are in transmission pole lines and in fence posts. Since the plant properties include approximately 8,000 acres, it is obvious that many, many feet of lumber find their way into fence lines.

In view of these conditions, it is not surprising that, in the three years from 1950 to 1952, inclusive, the Texas Division construction program consumed 448,031 linear feet of piling. As for poles, a single year's requirement, that for 1951, was 24,630 linear feet.

Whatever the end use for which it is intended, all structural wood in permanent installations in Dow's Texas Division plants is given preservative treatment. This has been standard procedure since 1947.

Persons not familiar with wood—or the plant environment—may think it odd that preservative treatment be made standard even for wood used above ground. The motive is easily demonstrated in the next few figures. Figure 2 presents an example of what happens to wood along the Gulf Coast showing a sill and window frame in a building in the plants. These framing members were untreated when installed about seven years before removal. But in that relatively short time, it had been completely riddled by decay. Figure 3, a view of overhead framing in a home near the plants, shows rather severe results of decay. This building was less than six years old when this photograph was taken. Figure 4 shows side framing in a plant building. The two members showing severe results of termite attack, after five years service, are the only untreated wood in view—and contrast sharply with the condition of the other members, which were preservative treated.

There are other attackers from which it is necessary to protect wood used in these plants. The plants produce chemicals, and the plant processes give rise to conditions which must be borne in mind in any use of wood. Here, as an example, Figure 5, is a series of stacks which were impregnated with a coal tar as protection against fumes from nearby processing.

Figure 6.—Coal tar impregnated timber decaying because of trapped moisture.

Figure 7.—View of treated wood test station, Lake Jackson, Texas.

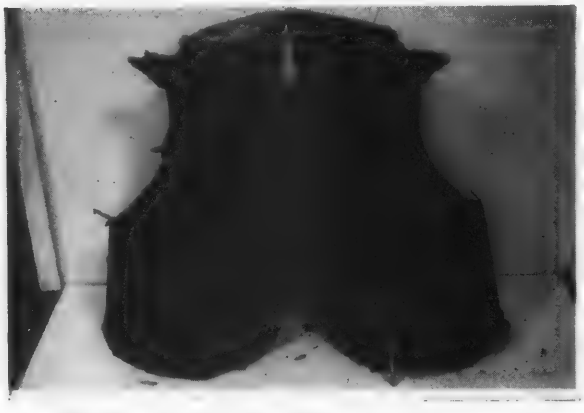

Figure 8.—Result of Limnoria damage on fourteen inch pile in six years.

Figure 9.—Bridge collapsed because of Limnoria damage to piling.

In some cases, a protective treatment has failed to give complete protection to lumber, as in the timber shown in Figure 6. A coal tar impregnation resulting principally in a surface coating was applied here, to protect against chemical damage; but the coating trapped moisture inside the timber, so that decay organisms destroyed it completely. This is an example of exposing a member to conditions for which it was not prepared.

This and similar cases of wood failure have given rise to serious, but probably familiar, questions on wood usage. Why, for instance, does a structural member give excellent service for twelve years while another—similarly treated and similarly exposed—fails in less than a year? Answers may not always be apparent: the protective coating or the preservative may have been short of specifications; the specifications themselves may be short of those actually required; the treatment may have been faulty; or the wood may have had imperfections that no treatment could overcome.

Test Program

Looking for a broader base of knowledge as a lead to better practices in wood usage, a test program has been undertaken in Dow's Texas Division. Figure 7 shows the test plot where various woods, in treated and untreated conditions, are compared for durability. Nearly 2,000 individual specimens are on exposure here, in tests aimed primarily at securing information to guide use of woods in inland locations, both above and in contact with the soil.

In the Texas Division plants, as previously mentioned, wide use is made of timber piling, much of which is in seawater. Failures which have occurred in such piling have a familiar cause—the limnoria, one-fifth of an inch in length, yet capable of reducing the diameter of piling as much as one inch a year. The pile in Figure 8 is an example; it was reduced from 14 inches to seven inches, in a period of six years.

When this type of damage is widespread, accidents like that shown in Figure 9 can be caused by the limnoria. Treatment of the bridge piling did not prevent damage and a failure that dropped a dragline into the water, fortunately without injury to any personnel.

For better pilings, as for better structural wood for other uses, the test program includes a marine borer test location. Nearly 400 specimens of treated wood are undergoing tests, including some that have been on exposure since 1947.

Results in these test programs have been guides in revising specifications for treatment of wood used in these plants. Generally speaking, three types of treatment—coal tar, creosote, and pentachlorophenol—have been basic since 1947, when the original set of specifications was adopted. Changes have been made as experience indicated and always with the goal that all wood be given the best possible preparation for the end use for which it is intended. These wood treatment specifications are set forth in an appendix to this paper. Briefly, for marine piling we use a mixture containing 70% Grade No. 1 creosote and 30% coal tar impregnating them to refusal. For lumber in contact with acids or acid environments a full cell treatment with coal tar is used. All other lumber poles, piles, cross arms, cross ties, siding, millwork, etc. is preservative treated with pentachlorophenol. The amount of retention speci-

Figure 10.—Walkway of treated wood installed in 1944.

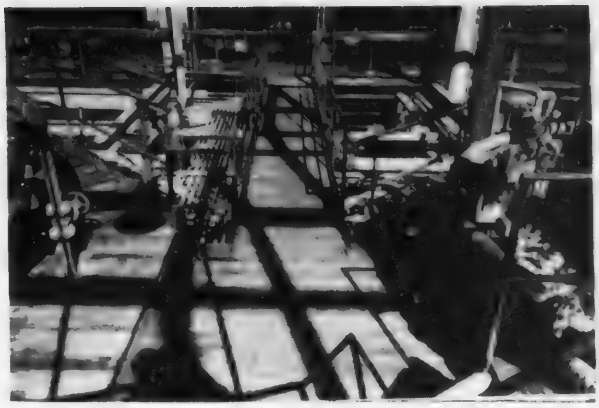

Figure 11.—Appearance of same walkway more than eight years later.

fied depends upon the severity of exposure.

It has been said that extensive use of wood is practiced in Dow's Texas Division structures. In some cases, there is little of the unusual in these uses of wood—as in these walkways of treated lumber. Figures 10 and 11 reflect experience in the use of such walkways. The pictures show the same structure at installation and after eight years service, with virtually no deterioration or wear visible.

It might also appear that the wood hand rails in Figure 12 offer nothing of special interest as a use of wood. But they are different. Originally, the hand rails in this structure were made of steel. But six or eight years after installation, and despite a vigorous and continuing program of painting, rust damage had so reduced the steel rails that they were replaced by a better material—treated wood.

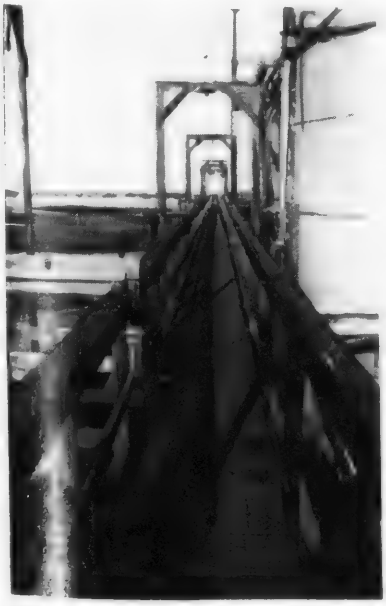

Figure 12.—Preservative treated wood hand rails which have replaced steel.

Similarly, the floor grating at a seawater intake (Figure 13) was also a steel structure when installed. Some six years later, the steel grating was removed and a wood grating, treated with pentachlorophenol, was installed. At the most recent inspection, after seven years of service, the wood grating was still rated as being in very good condition.

Perhaps there is some wonder as to precisely why steel must be replaced by wood. Atmospheric corrosion of metal is the general answer. For a more specific indication, consider these findings, of tests made over a seven-year period. To provide an international scale of comparison for conditions of atmospheric corrosion, a base value of "1" has been assigned to Khartoum, Egypt (2). In the tropical and marine climate of Singapore, the atmospheric corrosion is rated as "9". Pittsburgh, Pennsylvania, provides a more familiar example of an industrial area's atmospheric corrosion, having a rating of "65". In the area of the Texas Division plants, three ratings have been determined: twelve miles inland, it is "19"; one mile inland, it is "39"; in the heart of our processing areas, the rate reaches a staggering "501".

Figure 14 provides a close-up view of what can happen to steel under such conditions. Another example is the steel grating in Figure 15. Although this structure was given regular, periodic maintenance during six years in service, it corroded so severely that it gave way and caused a man to fall 15 feet. Wood has been substituted as the preferred material here.

There is one unique use of wood in the Dow plants. Figure 16 shows some propellers, wood propellers, that were originally made for use in a World War I airplane. They are re-worked to a new pitch, given some adjustment and then painted (Figure 17). Finally, these wood propellers go into service —as exhaust fans in a processing plant stack. They handle 130,000 cubic feet of gas per minute, cleaning out the moisture-laden gas and its small quantities of chlorine and hydrochloric acid. These propellers have given good service over extended periods.

Before concluding this report, it might be well to briefly consider some of the shortcomings noted in wood as used in the Texas Division. In this regard, chemical plant experience probably coincides closely with that of other industries.

Wood is easily worked, it is easily shaped, it is easily handled. But it is one of the most variable, highly non-uniform materials in the entire structural picture. Even from board to board, there are variations in important factors—as the possible causes of variation are so legion that absolute prediction of service results is all but impossible.

Furthermore, the results of protective and preservative treatments are not completely satisfactory. Treatment helps, and the practice of treatment of structural lumber is in no danger of discard. The increase in service life gained by treatment is a most positive advantage; but—particularly in the case of marine pilings—improved preservatives would be a boon to wood users.

Another of wood's shortcomings is vulnerability to fire. A fire recently occurred in a construction office in Dow's Texas Division. The destruction of this untreated wood building, while not a crippling or staggering loss, was a set-back in that many records, instruments and items of office equipment were also lost. Perhaps such fires as this will one day be reduced in severity, or even completely prevented, by the development of a preservative that also has fire-proofing qualities.

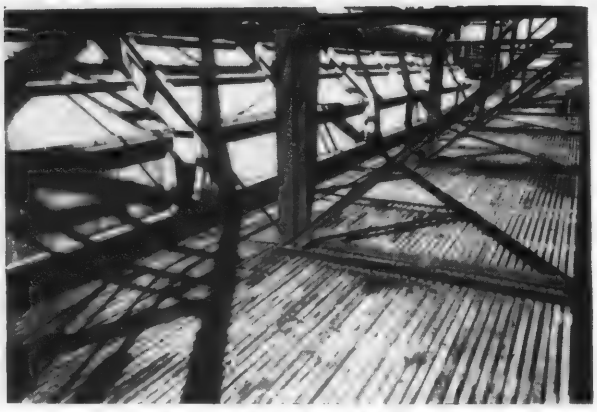

Figure 13.—Preservative treated wood floor grating which has replaced steel.

Figure 14.—Condition of steel hand rail compared to treated wood.

Figure 16.—View of wood propellers being repaired for use as process exhaust fans.

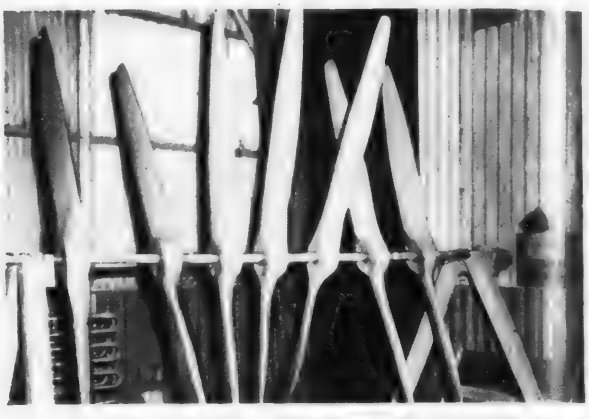

Figure 17.—Same propellers after repair and painting ready for service.

More Answers Needed

In closing, it should be emphasized that Dow's Texas Division plants are not unique in a widespread use of structural wood. This discussion covers only a few of the uses that Dow and other members of the chemical industry have found for forestry products. A strong belief that wood has positive advantages is demonstrated by the extent of the testing program undertaken in search of improvements for wood-using and wood-treating practices.

At the same time, it is safe to say that the chemical industry is looking to the forest products industry for the answers to some widespread problems. Given better woods, improved preservative treatments, and effective fireproofing, the chemical industry will obviously be ready to expand an already extensive use of wood in chemical processing plants.

Specifications For Wood Treatment[1]

Scope: All wood piles, service line poles, structural and other lumber including millwork shall be treated in accordance with these specifications as required for function, treatment method and treatment preservative when so specified on the drawings or bill of materials unless otherwise noted thereon.

Treated Wood Functions

Piles shall be southern pine or Douglas fir.

a) **Piles,** fresh water and foundation, which are to be capped below water—untreated.

b) **Piles,** fresh water and foundation, which are to be capped above low water level—shall be treated and penetrations shall conform to the A. W. P. A. Specification T3-49 "Standard Specification for the Preservative Treatment of Piles by Pressure Processes" to a minimum net retention of 12 lbs./cu. ft. of "5% penta* petroleum oil** solution".

c) **Piles,** for use in seawater, shall be treated and penetrations shall conform to A. W. P. A. Specification T3-49, "Standard Specification for the Preservative Treatment of Piles by Pressure Processes" to refusal (approximately 24 lbs./cu. ft. for pine) with a mixture containing 70% Grade No. 1 creosote and 30% coal tar. Piling treated with "5% penta petroleum oil solution" are not resistant to marine borers and are, therefore, not to be used in direct contact with seawater.

Figure 15.—Portion of steel grating which failed.

[1] The above typical specification was obtained from an industrial plant in the Gulf Coast area.

* The pentachlorophenol used shall conform to A. W. P. A. Specification P8-49 "Standard Specifications for Oil Borne Preservative".

** The oil used shall conform to A. W. P. A. Specification P9-49 "Standard Specification for Petroleum for Use with Pentachlorophenol and Copper Naphthanate".

Note: All retentions of preservative solutions are expressed in pounds of solution per cubic foot of wood except where otherwise indicated.

d) **Transmission or Service Line Poles,** southern yellow pine, shall be treated and penetrations shall conform to A. W. P. A. Specification T4-49, "Standard Specifications for the Preservative Treatment of Poles by Pressure Processes" to a minimum net retention of 12 lbs./cu. ft. of "5% penta* petroleum oil** solution".

Douglas fir shall be treated by an empty cell pressure process to a minimum retention of 8 lbs./cu. ft. of a "5% penta* petroleum oil** solution".

e) **Cross and Switch Ties,** southern yellow pine, oak, black, or red gum shall be treated and penetration shall conform to A. W. P. A. Specification T6-49, "Standard Specification for the Preservative Treatment of Crossties and Switch Ties by Pressure Processes" to a minimum retention of 8 lbs./cu. ft. for southern pine, black or red gum, 6 lbs./cu. ft. for red oak and to refusal for white oak with a "5% penta* petroleum oil** solution".

f) **Cross Arms, Douglas Fir,** shall be treated by pressure to a retention of 6 lbs./cu. ft. or by the hot and cold dip method using a minimum of two hours at 230° F. and two hours at 130° F. in a "5% penta* petroleum oil** solution". All boring and cutting shall be completed before treating.

Southern yellow pine shall be treated by an empty cell pressure process to a minimum retention of 8 lbs./cu. ft. of a "5% penta* petroleum oil** solution".

g) **Structural Lumber,** southern yellow pine, for use in cooling towers shall be treated by a method which shall give a minimum net retention of 12 lbs./cu. ft. of a "5% penta* petroleum oil** solution".

h) **Structural Lumber,** all species, and other wood construction material to be used in contact with the ground and exposures of similar severity, and not to be painted, shall be treated by a method which shall give a minimum net retention of 8 lbs./cu. ft. of "5% penta* petroleum oil** solution". For bridge material a minimum net retention of 12 lbs./cu. ft. shall be used. Where an especially clean treated wood is desired, the oil shall meet A. W. P. A. Specification P9–49, Section B.

i) **Structural Lumber,** all species, for exterior and interior use, to be painted, varnished, or left unfinished shall be treated by a method resulting in a net retention of 24 gallons per thousand board feet of water repellent preservative containing 5% chlorinated phenols. (In the case of "difficult to treat" wood such as Douglas fir the treatment shall be to refusal if a retention of 24 gallons per thousand board feet cannot be attained.)

j) **Millwork** shall be dipped into a water repellent preservative solution containing 5% chlorinated phenols according to the National Woodwork Manufacturers Association for a minimum period of three (3) minutes.

k) **Structural Lumber,** all species, for exposure to extreme alkali or acid conditions shall, after proper seasoning, be impregnated by immersing in a vat of crude paraffin at a minimum of 250° F. for 72 hours. Then the temperature of the bath shall be lowered to 190° F.

l) **Structural Lumber,** to be used in contact with acids or acid environments shall be treated by a full cell pressure treatment using coal tar. This process is known as niggerizing.

Bibliography

1. Smith, F. B., and Olson, G. E., The Dow Chemical Company *Pentachlorophenol Increases Fence Post Service Life,* DOWN TO EARTH, *3* (2) 10–12 (1947).
2. Larrabee, C. P., *Corrosion of Steels in Marine Atmospheres and the Transactions of Electrochemical Society,* 87, 163 (1945).

Discussion

E. D. Marshall (Consultant in Forest Products, Lufkin, Texas): Are your cooling towers made from redwood?

Mr. Volkening: Yes.

Mr. Marshall: Have you experienced any trouble with deterioration of redwood in your cooling towers? The Humble Oil Company in Texas has experienced deterioration of redwood in cooling towers. Several years ago they tested creosoted wood for this purpose. I do not know the results of their test.

Mr. Volkening: We have had no difficulty with deterioration of our redwood cooling towers. We have impregnated redwood with pentachlorophenol on an experimental basis.

Ralph Bescher (Koppers Company): How long have your redwood cooling towers been in service?

Mr. Volkening: About seven years.

R. C. Musslewhite: Do you have any problem in obtaining insurance on your wood structures at your chemical plant?

Mr. Volkening: I do not have the answer to that question.

R. C. Musslewhite (Southern Pine Lumber Company, Diboll, Texas): Our company has just completed an expansion and modernization project and all construction was of steel and concrete due to an insurance advantage of roughly 5 to 1 in favor of steel construction.

Delignification of Spruce Sawdust with Chlorine Dioxide[1]

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Research Chemist and Laboratory Supt., respectively, Ottawa Laboratory, For. Prod. Lab. Div., Forestry Branch, Department of Resource and Development, Ottawa, Ont.

Spruce sawdust has been delignified on a laboratory scale, with chlorine dioxide as the delignifying agent. Results of many variations in technique are shown. A multi-stage laboratory procedure was developed which included acid and alkali pre-treatments, followed by two chlorine dioxide stages, with an intermediate alkali treatment. Using 20–27 percent chlorine dioxide, it was possible to obtain white pulps in 40–49 percent yield with alpha-cellulose values up to 87.5 percent. Results are also reported for a few preliminary experiments on alkaline purification of pulps secured and on evaluation of these pulps for acetylation purposes.

Introduction

THE DEVELOPMENT of profitable outlets for sawdust is a major problem in wood waste utilization. Relatively small quantities enter into the production of fuel logs and into certain types of wallboards and building blocks, and some sawdust is ground to wood flour. At present, the only large use is as home and industrial fuel, and this is considered to be a low-value use. Sawdust has also been pulped with standard size chips (1) but the product was suitable only for use in certain low-grade papers.

The hesitancy to use sawdust as a source of cellulose is attributable to difficulties of processing in standard pulping equipment, dirt content, and shortness of fibres for use in paper products. Delignification of sawdust by standard commercial methods of pulping may prove difficult because of clogging of the digesters and over-cooking of the fine particles. However, with chlorine dioxide as a delignifier, it is believed that some of the engineering difficulties normally encountered in the handling of sawdust could be overcome through the use of non-pressure pulping equipment. Excessive degradation of cellulose in the fine particles could possibly be avoided. There is an increasing tendency towards barking sawlogs, and sawdust from barked logs is of a much higher state of purity. The development of a process to convert sawdust into cellulose for the ultimate use of the cellulose where length of fibre is not important is considered to be an advance in the right direction. Possible outlets for such cellulosic material may be found in the rayon, lacquer, plastics, and explosives fields.

Chlorine dioxide has been known as a delignifying agent for some time. In 1921 Schmidt (2) used this reagent in dilute acetic acid to obtain what he termed the "Skelettsubstanz" of wood. This work was further studied in the next few years (3) (4). Then in 1931, Schmidt and co-workers (5) published a revised method of obtaining the "Skelettsubstanz" by treating wood at room temperature for 17–26 days with an aqueous solution of chlorine dioxide buffered with pyridine.

In 1942 Jayme (6) described a method of isolating holocellulose using sodium chlorite in dilute acetic acid at 60° C. for a total of 40 hours. Wise (7) revised this method slightly, using 60° C. for a short period followed by 24 hours at 30° C. The following year, Wise and co-workers (8) published their method of holocellulose determination which required only a total of 4 hours at 70–80° C. They used 120% sodium chlorite (based on the weight of wood) in dilute acetic acid solution. Lovell (9) prepared holocellulose from softwoods using sodium chlorite solutions

Table I – Effect of Particle Size in Single Stage Chlorine Dioxide Delignifications of Spruce Sawdust*

Run	Particle Size	Yield	Alpha-Cellulose	Lignin	Colour
No.	mesh	per cent	per cent	per cent	
1	4 - 6	67.0	61.2	1.8	faintly yellow
2	6 - 10	67.1	60.4	1.9	" "
3	10 - 20	65.0	62.5	1.7	" "
4	20 - 40	65.5	62.3	1.9	" "
5	over 40	65.3	61.8	1.6	" "

* 10 gm. of spruce sawdust was treated at 80°C. for 3 hours with 67.5% chlorine dioxide in 750 cc. of solution containing 14 gm. of sodium acetate buffer.

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ABOUT THE AUTHOR: SCHWARTZ, H. Attended McGill Univ., Montreal. Received PhD in wood chemistry. Has had some 15 papers published in fields of organic chemistry, chemical utilization of wood and bleaching of kraft pulp. Member: Fundamental Research Committee, Technical Section, CPPA; Program Committee, Cellulose Division, American Chemical Society; Chemical Institute of Canada; Chairman, Fiberboard Specification Committee, Canadian Government Specifications Board; FAD Panel on Wood Chemistry.

Table II - Results of Three-stage Treatments for Delignification of Spruce Sawdust in Buffered Chlorine Dioxide Solutions.

Run	Delignification Stages[a]			Yield	Alpha-cellulose	Lignin	Permanganate Number	Colour
	First ClO_2[b]	Intermediate Alkali[c]	Second ClO_2[b]					
No.	per cent		per cent	per cent	per cent	per cent		
6	13.5	0.5% at 100°C., 2 hr.	13.5	67.5	71.5	2.2	3.94	yellowish
7	13.5	1.0% at 100°C., 2 hr.	13.5	63.6	73.7	1.5	3.76	yellowish
8	13.5	0.5% at 125°C., 1 hr.	20.3	64.3	69.3	0.5	2.99	slightly yellow
9	21.6	1.0% at 100°C., 2 hr.	21.6	58.2	70.3		2.16	white

(a) 100 cc. of liquor was used for 10 gm. of sawdust in all stages of the delignification.

(b) The quantity used is expressed as a percentage of the weight of sawdust.

(c) The percentage is expressed as concentration of alkali in solution.

Table III - Effect of Various Pretreatments on Multi-stage Delignifications of Spruce Sawdust in Buffered Chlorine Dioxide Solutions.

Run	Pretreatment[a]		Delignification Stages[a]			Yield	Alpha-cell.	Permanganate number	D.P.	Colour
	Sulphuric Acid[c]	Alkali[c]	First ClO_2[b]	Intermediate Alkali[c]	Second ClO_2[b]					
No.			per cent		per cent	per cent	per cent			
10		2.0% at 100°C., 2 hr.	13.5	2.0% at 100°C.,2.5 hr.	13.5	47.0	79.4		2520	white
11	1.0% at 100°C.,2 hr.	2.0% at 100°C., 2 hr.	"	"	"	35.1	87.6		1181	white
12	0.1% at 100°C.,1 hr.	1.0% at 100°C., 1 hr.	"	1.0% at 100°C., 1 hr.	10.1	49.4	76.8	1.80		white
13	0.5% at 100°C.,1 hr.	"	"	"	"	45.0	83.5	1.41	1560	white
14	1.0% at 100°C.,1 hr.	"	"	"	"	42.8	83.1	1.47	1550	white
15	1.0% at 100°C.,1 hr.	0.25% at 100°C.,1 hr.	"	"	"	47.6	83.2	1.48		white
16	0.5% at 100°C.,1 hr.	"	"	"	"	47.2	80.2	1.82	2030	white
17	1.0% at 125°C.,1 hr.	1.0% at 125°C., 1 hr.	"	"	"	34.6	87.0			white
18	1.0% at 125°C., 0.5 hr.	1.0% at 125°C., 0.5 hr.	"	"	"	39.6	86.5	1.07	1375	white

(a) 100 cc. of liquor was used for 10 gm. of sawdust.

(b) The quantity used is expressed as a percentage of the weight of sawdust.

(c) The percentage is expressed as concentration of alkali or acid in solution.

buffered with acetic acid to a pH of 5. At 60–70° C., about 20 hours was required for complete delignification. However, with complete removal of the lignin a certain quantity of polysaccharide was also removed. Runkel (10) subjected wood chips, pretreated with alkali, to sodium chlorite in acetic acid at pH 4–5 and 60–70° C. Repeated chlorite treatments yielded a pulp which was claimed to be free of lignin and only slightly degraded. Since then, sodium chlorite has been used frequently in pulping where the retention of hemicelluloses is desired and the cellulose degradation is to be kept to a minimum (11) (12) (13). Most of the workers who used sodium chlorite for this purpose (7) (10) (14) claimed that the delignification was actually carried out by the chlorine dioxide liberated in acid solution.

Very little has been published on the use of chlorine dioxide itself as a pulping agent. Holmberg and Jahn (15) (16) pulped sawdust and ground wood with chlorine dioxide in aqueous pyridine solutions. They used 60–70% of chlorine dioxide (based on the weight of wood) at 20° C. for 8 days and obtained pulps from white pine sawdust with practically no cellulose degradation and 1.07–1.86% lignin. Under similar conditions aspen yielded a pulp with 0.17% lignin.

The high cost and large amounts (100–150%) of sodium chlorite necessary for pulping wood has made its use prohibitive, except in the laboratory. Although chlorine dioxide is still rather expensive it can apparently now be manufactured almost as cheaply as chlorine (17). It is now used in increasing amounts as a bleaching agent to remove the last residues of lignin and coloring materials from wood pulp. Sodium chlorite for this purpose is only used where the generation of chlorine dioxide on a commercial scale is impractical.

Discussion

In the present investigation, chlorine dioxide was generated in small quantities and used in delignifying spruce sawdust produced on resaws in a typical mill operation and free from bark. The sawdust used had the following screen analysis:

4– 6 mesh	3.5%
6–10 mesh	14.6%
10–20 mesh	38.3%
20–40 mesh	28.2%
smaller than 40 mesh	15.4%

Most of the work reported in this paper was of an exploratory nature. The prime aim was to produce a pulp of high purity and in reasonably good yield. The cellulosic products were evaluated by yield, alpha-cellulose content, lignin content, degree of polymerization (D. P.), and permanganate number determinations. These analyses only provided indications of the types of pulps that could be obtained by various treatments. A few tests on

Table IV - Effect of Variations in Concentration of Chlorine Dioxide on Multi-stage Delignifications of Spruce Sawdust in Buffered Solutions.

Run	Pretreatment(a)		Delignification Stages(a)			Yield	Alpha-cell.	Permanganate number	D.P.	Colour
	Sulphuric acid(c)	Alkali(c)	First ClO_2(b)	Intermediate Alkali(c)	Second ClO_2(b)					
No.			per cent		per cent	per cent	per cent			
19	1.0% at 100°C., 1 hr.	1.0% at 100°C.,1 hr.	13.5	1.0% at 100°C., 1 hr.	13.5	42.7	83.5	1.20	1640	white
20	"	"	"	"	10.1	42.8	83.1	1.47	1810	white
21	"	"	"	"	6.8	43.8	82.9	1.93	2395	faintly yellow
22	"	"	10.1	"	10.1	42.2	82.0	2.98	2415	brownish
23	"	"	"	"	6.8	46.9	81.5	3.77		brownish
24	1.0% at 125°C.,0.5 hr.	1.0% at 125°C.,0.5 hr.	13.5	"	10.1	39.6	86.5	1.07	1375	white
25	"	"	"	"	6.8	40.6	86.4	1.28	1690	white with yellow specks

(a) 100 cc. of liquor was used for 10 gm. of sawdust.

(b) The quantity used is expressed as a percentage of the weight of sawdust.

(c) The percentage is expressed as concentration of alkali or acid in solution.

the suitability of some of the pulps for acetylation purposes have been made. These are also reported herein. More extensive experiments on large quantities of material are being carried out to permit evaluation of the pulps for specific purposes, and it is intended to report results at a later date.

Single Stage Chlorine Dioxide Treatments

The first series of experiments was conducted in Erlenmeyer flasks, stoppered with small inverted flasks, and consisted of single treatments with large quantities of chlorine dioxide. Ten grams of sawdust was heated at 80° C. for 3 hours with 67.5% chlorine dioxide (based on the weight of sawdust) in 750 cc. of solution. During this time, the reagent was completely consumed and the pH in an unbuffered solution dropped from 3.7 to 1.0. The final product was yellow-brown in color. However, if 14 gm. of sodium acetate buffer was added to the solution at the start of the treatments, the pH dropped from 6.1 to 4.2. The pulps from the buffered solutions were only faintly yellow in color and the lignin contents were slightly lower than from the unbuffered treatments. A very slight excess of chlorine dioxide appeared necessary to ensure production of a relatively soft, fairly white pulp. At a higher temperature (92° C.), the reaction was more rapid and the sawdust was largely delignified within 2 hours.

(a) Effect of Particle Size: A series of experiments was carried out to determine the effect of sawdust particle sizes on the properties of the pulps obtained. The results, Table I, indicate that the size differences studied have no serious effect on the properties of the final products. Using samples varying in size from 4 mesh to finer than 40 mesh, the lignin content of the pulps remained in the range of 1.6–1.9%, the alpha-cellulose content 60–63%, and the yield 65–67%. In a further experiment, wood particles ranging from 4 mesh to standard ¾" chips were submitted to the same treatment. In these, the penetration of liquor was poor and the interior of the particles was unpulped indicating that chlorine dioxide is not satisfactory for pulping large particles by this method. Although results shown in Table I indicate that a composite sawdust fraction would probably be suitable for delignification by chlorine dioxide, the 10–20 mesh sawdust fraction was used in all subsequent work.

(b) Effect of Pretreatments and Post-treatments with Alkali: If any of the pulps from a single stage chlorine dioxide treatment were treated at 100° C. for 4 hours with a 10:1 ratio of 1% sodium hydroxide solution, the yellow or brownish color of the pulps was readily removed and the alpha-cellulose value was raised from 58–63% to 83–86%. Yield of these purified pulps based on the sawdust was around 40%. If the sawdust is treated with 1% sodium hydroxide solution before the chlorine dioxide digestion, a very white pulp with 0.4% lignin is obtained using only 54% chlorine dioxide. Both the pretreated and post-treated pulps contained practically no alcohol-benzene extractives, whereas the yellowish pulps without these treatments contained 7–10% solubles. These were probably lignin degradation products which were insoluble in water but soluble in alkali, alcohol-benzene, and the 72% sulphuric acid used to determine Klason lignin.

Multi-stage Delignification Procedures

From the work just described, it is apparent that a considerable amount of reagent was necessary to delignify sawdust when a single chlorine dioxide treatment was used. Even after a pretreatment with alkali, about 50% was required: an amount which would appear to make a commercial process unattractive. However, it is known (18) that chlorine dioxide will degrade lignin first to alkali soluble materials and then to water solubles. Thus, if a single stage treatment is used, a considerable amount of chlorine dioxide is consumed in converting the alkali soluble product to water solubles. By using a mild chlorine dioxide treatment followed by an alkali wash, much of the lignin is solubilized. Very little additional chlorine dioxide is then required to remove the remaining lignin.

In the multi-stage studies, different equipment was used for treatment with chlorine dioxide than in the single-stage experiments. Instead of treating in Erlenmeyer flasks, 200 cc. bottles which could be tightly sealed were used so as to avoid loss of chlorine dioxide into the air; although Erlenmeyer flasks gave similar results with comparable runs. In these experiments, the sawdust was treated for 30 minutes with chlorine dioxide at 80° C., followed by treatments with dilute sodium hydroxide solution and then chlorine dioxide again for 1 hour. The following work is designed to indicate the effect of variations in the delignification treatments and also of pretreatments. In all cases, 10 gm. of sawdust and 100 cc. of solution were used.

(a) Results of 3-stage Treatments: In Table II are shown results of s.v-

Table V - Effect of Change in Concentration of Intermediate Alkali Treatment on Multi-stage Delignifications of Spruce Sawdust in Buffered Solutions.

Run	Pretreatment(a)		Delignification Stages(a)			Yield	Alpha-cell.	Permanganate number	D.P.	Colour
	Sulphuric Acid(c)	Alkali(c)	First ClO_2(b)	Intermediate Alkali(c)	Second ClO_2(b)					
No.			per cent		per cent	per cent	per cent			
26	1.0% at 100°C., 1 hr.	1.0% at 100°C., 1 hr.	13.5	0.5% at 100°C., 1 hr.	10.1	45.1	81.2	1.32	1980	white
27	"	"	"	1.0% at 100°C., 1 hr.	"	42.8	83.1	1.47	1810	white
28	"	"	"	2.0% at 100°C., 1 hr.	"	40.0	85.5	0.99	1745	white

(a) 100 cc. of liquor was used for 10 gm. of sawdust.

(b) The quantity used is expressed as a percentage of the weight of sawdust.

(c) The percentage is expressed as concentration of alkali or acid in solution.

eral multi-stage delignification experiments without pretreatments and involving the use of 27–43.2% chlorine dioxide. In all these experiments, 3 gm. of sodium acetate was used as buffer. Except for run 9 in which a large amount of chlorine dioxide was used, the pulps were all slightly colored and contained less than 74% alpha-cellulose. The lignin content decreased with the use of more drastic intermediate alkali treatment (runs 6 and 7), or as more chlorine dioxide was used (runs 8 and 9). The permanganate numbers in these runs also decreased correspondingly with the decrease in lignin content. Since the permanganate number determinations were much more rapid and reproducible when the lignin content was low they were used instead of Klason lignin determinations in most subsequent work. Furthermore, Klason lignin determinations on cellulose obtained from chlorite treatments have been shown to be unreliable (19) because of the presence of acid soluble lignin products.

The pulps from these multi-stage treatments have higher alpha-cellulose contents (69.3–73.7%) than the pulps from the single stage experiments (60.4–62.5%). However, the chief advantage lay in the reduction of the amount of chlorine dioxide required; from 67.5% to as low as 27%.

(b) Effect of Pretreatments on Multi-stage Delignifications: Although the consumption of chlorine dioxide could be greatly reduced by the three-stage process used, the alpha-cellulose content and purity of the cellulose product was still not very high. In attempting to further reduce the amount of chlorine dioxide necessary, and also to raise the purity of the pulps, a series of experiments was carried out involving pretreatment of the sawdust with dilute sodium hydroxide solution and dilute sulphuric acid. The results are given in Table III. The use of the acid in conjunction with the alkali pretreatment appears desirable, as indicated by results from runs 10 and 11. The acid hydrolysis prior to the alkaline treatment caused a considerable rise in the alpha-cellulose content of the pulp. However, the D. P. was lowered at the same time, thus indicating a certain amount of degradation by the acid treatment. In runs 12 to 18, attempts were made to reduce the amount of degradation and retain the relatively high alpha-cellulose content of the pulps. To these ends, lower amounts of chlorine dioxide and less severe intermediate alkali treatments were used along with variations in the pretreatments. As the concentration of the acid solution in the pretreatment was increased from 0.1 to 1.0% (runs 12 to 14), the yield decreased but the alpha-cellulose values and permanganate numbers of runs 13 and 14 remained relatively constant. The highest alpha-cellulose contents and lowest permanganate numbers in this series of experiments were obtained by using pretreatments at 125° C. (runs 17 and 18). The higher yield of run 18 indicated less degradation during the shorter pretreatment time.

These experiments made it evident that acid and alkali pretreatments were desirable for the production of pulps with relatively high alpha-cellulose contents. In general, as the concentration or temperature of the pretreatments was increased, the yield of pulp was lowered but the alpha-cellulose content was raised. The D. P. values were also lowered by the more drastic pretreatments, indicating a certain amount of degradation. However, even at 125° C. or when using 2% alkali, the D. P. did not drop below 1100. This value is not too low for many commercial purposes.

(c) Effect of Variation in Chlorine Dioxide Concentration on Multi-stage Delignifications: Reducing the total quantity of chlorine dioxide used from 27.0% to 20.3% (runs 19, 20, and 21, Table IV), left the yield and alpha-cellulose contents of the pulps relatively constant. However, the increase in D. P. as less chlorine dioxide was used indicated that excess reagent causes some breakdown in the chain length of the cellulose. At the same time, the permanganate numbers, although low in every case, increased as the chlorine dioxide concentration used was decreased. When the 20.2% chlorine dioxide was divided evenly in the two stages (run 22), the increased permanganate number and brown color of the pulp indicated incomplete delignification. Similarly, the use of 16.9% chlorine dioxide (run 23) resulted in a higher permanganate number and the pulp definitely was not completely delignified.

The effect of variation in total chlorine dioxide concentration, when using more severe pretreatments, is indicated by runs 24 and 25 in Table IV. Trends are similar to those of runs 20 and 21, although the values are different.

(d) Effect of Change in Concentration of Intermediate Alkali Treatment: In the experiments shown in Table V, the concentration of alkali solution in the intermediate treatment was varied from 0.5 to 2.0%. As the concentration increased, the yield dropped from 45.1 to 40.0% but the alpha-cellulose content rose from 81.2% to 85.5%. The D. P. values decreased very slightly as stronger alkali treatments were used.

(e) Effect of Buffer in Multi-stage Chlorine Dioxide Delignifications: A series of experiments was carried out to determine the effect of the use of a buffer in the multi-stage chlorine dioxide treatments. Results are shown in Table VI. With 3 gm. of sodium acetate as buffer, the pH of the first stage chlorine dioxide treatment dropped to 4.2 and that of the second stage to 3.6. The use of calcium acetate produced similar results. When no buffer was used in the chlorine di-

Table VI - Comparison of Multi-stage Delignifications of Spruce Sawdust using Buffered and Unbuffered Solutions.

Run	Pretreatment[a]		Delignification Stages[a]			Yield		Alpha-cellulose		Permanganate number		D.P.	
	Sulphuric Acid[c]	Alkali[c]	First ClO_2[b]	Intermediate Alkali[c]	Second ClO_2[b]	Unbuff.	Buff.	Unbuff.	Buff.	Unbuff.	Buff.	Unbuff.	Buff.
No.			per cent		per cent	per cent	per cent	per cent	per cent				
29	1.0% at 100°C., 1 hr.	1.0% at 100°C., 1 hr.	13.5	1.0% at 100°C., 1 hr.	13.5	44.1	42.8	81.2	83.1	1.68	1.47	1550	1550
30	"	"	10.1	"	10.1	44.3	42.2	78.9	82.0	2.42	2.98	1098	2415
31	"	"	13.5	0.5% at 100°C., 1 hr.	"	45.2	45.1	78.7	81.2	1.57	1.32	1210	1980
32	1.0% at 125°C., 0.5 hr.	1.0% at 125°C., 0.5 hr.	"	1.0% at 100°C., 1 hr.	"	39.6	39.6	85.4	86.5	1.14	1.07	1100	1375

(a) 100 cc. of liquor was used for 10 gm. of sawdust.

(b) The quantity used is expressed as a percentage of the weight of sawdust.

(c) The percentage is expressed as concentration of alkali or acid in solution.

oxide solutions, the pH dropped to 1.2 during the first stage and to 1.0 in the second. The yields of pulps from these unbuffered treatments were, unexpectedly, either the same or slightly higher than yields from buffered solutions. However, the alpha-cellulose contents were lower in every case and the lower D. P. values of the pulps indicated that some hydrolysis had occurred in the acidic chlorine dioxide liquors. In most cases, although the differences were small, the permanganate numbers of the pulps from the unbuffered solutions were slightly higher, indicating more impurities. Thus the pulps from buffered solutions were slightly superior to those from unbuffered solutions in alpha-cellulose content, permanganate number, and D. P., but were obtained in slightly lower yields.

Purification of Pulps Obtained from the Multi-stage Chlorine Dioxide Process

In an attempt to raise the alpha-cellulose content of chlorine dioxide pulps beyond 90%, several pulp samples were treated with alkali solutions. Since only small samples of any one pulp were available for the alkali treatments, no systematic study of varying conditions on a single pulp could be made. In lieu of this, various alkali treatments were carried out on different pulps so as to obtain some indication of methods which might produce pulps with high alpha-cellulose content. The results appear in Table VII. In samples 1 to 9, hot dilute treatments consisting of 0.5 to 1.0% solutions of sodium hydroxide at 80–140° C. were used. None of these produced pulps with alpha-cellulose contents above 88.7%. On the other hand, in samples 10 to 12 using a cold concentrated alkaline solution the alpha-cellulose values of pulps with both low and high alpha-cellulose contents could be raised to 93–95%. Richter (20) also found that certain pulps were more easily purified by a cold concentrated treatment than by a hot dilute method. The loss of alpha-cellulose in these experiments can be seen by comparing the yield of alpha-cellulose (based on the wood) before and after purification. In the cold concentrated method, and hot dilute method at temperatures up to 100° C., the loss was small. In the latter method, the loss increased when temperatures above 100° C. were used.

Acetylations of Chlorine Dioxide Pulps

In order to obtain an indication as to the suitability of chlorine dioxide pulps for acetylation purposes, several pulps were evaluated by a modification of the method described by Heuser, Shockley and Van Den Akker (21). Rather than evaluate the turbidity after centrifuging at 2,000 r.p.m., the solution was cleared completely at 13,000 r.p.m. and the residue weighed. A pulp from the multi-stage process, involving in its preparation no pretreatments, the use of a total of 27% chlorine dioxide, and

Table VII - Alkaline Purification of 1 gm. Samples of Chlorine Dioxide Pulps.

Sample	Purification Treatment	Alpha-cellulose content		Yield of Alpha-cellulose based on wood	
		Original Pulp	Purified Pulp	Original Pulp	Purified Pulp
No.		per cent	per cent	per cent	per cent
1	50 cc. of 1% NaOH at 140°C., 1 hr.	73.4	82.8	44.0	38.0
2	"	71.5	82.1	47.9	39.8
3	50 cc. of 1% NaOH at 125°C., 1.5 hr.	73.7	82.8	47.0	40.1
4	25 cc. of 1% NaOH at 125°C., 1 hr.	84.5	87.5	32.6	27.3
5	25 cc. of 1% NaOH at 100°C., 1 hr.	87.6	88.7	30.8	30.0
6	"	79.4	83.5	37.3	35.8
7	20 cc. of 0.5% NaOH at 80°C., 4 hr.	83.5	88.7	36.3	34.3
8	"	73.7	81.0	37.8	36.8
9	"	70.3	78.0	41.0	39.2
10	10 cc. of 10% NaOH at 20°C., 1 hr.	71.5	93.0	47.9	45.2
11	"	82.0	95.0	38.0	37.0
12	"	86.5	94.5	34.2	33.0

having 76.5% alpha-cellulose, left a residue of 57.6% after acetylation. The pulp from run 10, Table III, which had an alkali pretreatment and only a slightly higher alpha-cellulose content, left a residue of 36% after acetylation. Both of these pulps would be considered poor for acetylation purposes. However, the pulp from run 1, Table III, which had both an acid and alkali pretreatment and an alpha-cellulose content of 87.6%, was much more suitable for acetylation, leaving only a 5.6% residue after centrifuging. A commercial viscose pulp when tested similarly left a 7.5% residue. On the other hand, cotton linters, a sulphate pulp prepared from sawdust, and a very highly purified sulphite pulp left no residue. It is probable that any chlorine dioxide pulp with a high alpha-cellulose content would prove suitable for acetylation. However, results just cited are very preliminary and further experimental work is being carried out.

Experimental Methods

Preparation of Chlorine Dioxide: Sixty-seven grams of potassium chlorate was mixed with 53 gm. of oxalic acid in a blackened 500 cc. round bottomed flask. To this was added 215 cc. of cooled sulphuric acid solution containing 74 cc. of concentrated acid. The reaction usually started in the cold but required some heat (50–60° C.) after about an hour to sustain the evolution of the gas. The gas was bubbled through a solution of concentrated sodium chlorite to remove any chlorine and then passed through an air trap to catch any solution which might be blown over by the gas. It was collected in 1000 cc. of cool distilled water and stored in a refrigerator until required. To determine the amount of chlorine dioxide present, 2 cc. of solution was removed and add to about 25 cc. of water. About 1 gm. of potassium iodide and 15 cc. of 10% sulphuric acid were added and the liberated iodine was titrated with 0.1 N sodium thiosulphate solution. Since the equivalent weight of chlorine dioxide is one-fifth of its molecular weight in this reaction, the weight of chlorine dioxide could then be calculated as being:

$$\frac{\text{Vol. of thiosulphate} \times \text{Normality}}{1000} \times \frac{67.5}{5}$$

Chlorine Dioxide Treatments: The chlorine dioxide treatments were conducted in containers placed in a thermostatically controlled water bath. The acid and alkali treatments were conducted in Erlenmeyer flasks on a steam bath, or in pressure bottles in an oil bath when temperatures above 100° C. were used. The products of the various stages of delignification were removed on sintered glass funnels and washed well with about 500 cc. of water. The final product was dried *in vacuo* at 45° C. for 36 hours.

Acetylation and Evaluation of Chlorine Dioxide Pulps: The method suggested by Heuser, Shockley and Van Den Akker (21) was greatly modified for this work. To half a gram of pulp in a 50 cc. round bottomed flask was added 12.5 cc. of glacial acetic acid. The flask was stoppered and heated for 5 hours on a steam bath. The solid was then removed on a sintered glass crucible, well washed with acetic acid, replaced in the flask, and 2.5 cc. of actic acid added. After standing overnight, 10 cc. of a solution of acetic acid containing 0.125 cc. of sulphuric acid was added and the mixture well shaken for 5–10 minutes. Acetic anhydride (3.5 cc.) was then added, with cooling to keep the temperature at approximately 20° C. The flask was shaken for 1 hour at room temperature and finally placed in a chamber at 35° C. for 5 hours. At the end of this time, the contents of the flask were quantitatively washed into the stainless steel tube of a high speed cenrtifuge and centrifuged at 13,000 r.p.m. for 5 minutes. The supernatant liquor was removed and the solid, if present, was washed in the tube with more acetic acid. Any solid remaining was transferred to a tared sintered glass crucible, washed with acetic acid (50 cc.), and dried in vacuo at 45° C. for 36 hours. The percentage of residue was calculated on the weight of pulp used in this treatment.

Methods of Analyses: The alpha-cellulose determinations were conducted as described in the TAPPI Standards, except that one gram of sample with one-third of the other specified quantities was used.

The Klason lignin determinations were also conducted as described in the TAPPI Standards but with half quantities. The preliminary solvent extraction was eliminated and sintered glass crucibles were used instead of the alundum or Gooch crucibles suggested.

Most of the viscosity measurements from which the D. P. values were calculated were made by the cupriethylenediamine method. Since the pulps were not readily soluble in this solution, a revised method described in the TAPPI Standards (22) was found to be satisfactory. The pulp (0.090 gm.) was wetted in a 50 cc. Erlenmeyer flask with 15 cc. of cupriethylenediamine solution diluted to be 0.167 molar in copper. After standing 5–10 minutes, 10 cc. of the 1 molar solution was added, thus making the resulting solution 0.5 molar in copper. The flask was flushed with nitrogen and then shaken for 30 minutes or more. The pulps readily dissolved and the viscosities were determined at 25° C. in a Cannon-Fenski modification (23) of the Ostwald viscosimeter. The specific viscosity was determined, and from this, the D. P. was calculated as:

$$\text{D. P.} = \frac{\eta sp}{K_m C}$$

Where C is the concentration in grams per litre and K_m is 8×10^{-4}.

Summary and Conclusions

In laboratory experiments, chlorine dioxide has been found to be a suitable reagent for the delignification of a finely divided material such as spruce sawdust. In a one stage delignification treatment, it has been found necessary to use a very large amount of chlorine dioxide based on the weight of the wood, i.e., about 67.5%. A multistage laboratory procedure has been developed involving pretreatments with 0.1 to 1% solutions of sulphuric acid, and 0.25 to 1.0% solutions of sodium hydroxide, followed by two delignification treatments with chlorine dioxide with an intermediate alkali stage. While neither the pretreatments nor the conditions of the various stages in the delignification are considered by any means to be optimum, the main feature of the technique is the fact that the amount of chlorine dioxide consumed was reduced from about 67.5% to the range of 20 to 27%. By the process used, pulps were obtained in 40 to 49% yield with alpha-cellulose contents ranging from 77 to 87%. The D. P. values of most of these pulps ranged from 1400 to 2000, the higher values being obtained when lower amounts of chlorine dioxide were used. The use of less than 20% chlorine dioxide under the conditions studied was found to be insufficient, producing a brown product with a relatively high permanganate number.

The exclusion of the use of buffer in the chlorine dioxide delignification treatments caused some hydrolysis of the cellulosic material, but none of the pulps studied suffered degradation sufficient to seriously affect the properties of the pulps.

Many of the pulps mentioned above might have suitable properties for use in the manufacture of lacquers or

plastics. For their use in the manufacture of rayon or for certain esterification processes, pulps with 93 to 95% alpha-cellulose can be obtained by the use of a cold concentrated alkaline purification treatment. While preliminary experiments on acetylation of high alpha pulps have given promising results, more extensive experimental work is being carried out on relatively large quantities of material for evaluation for specific chemical purposes.

It is emphasized that all results reported in this paper were obtained from small scale laboratory experiments, with little thought given to industrial implications. Although chlorine dioxide at present is a rather expensive reagent, it is believed that the price may be lowered considerably by the development of improved techniques for its generation. Reduction to the 20% range of the amount of chlorine dioxide required for the delignification of sawdust, with the possibility of even further reduction, would appear to make a process involving this reagent somewhat more attractive. A favorable feature in the use of chlorine dioxide lies in the fact that it involves delignification at relatively low temperatures and at atmospheric pressure. In addition, there is a continually increasing quantity of sawdust available in relatively pure form owing to the recent trend of many large sawmills to bark their logs prior to sawing. From the foregoing, there appears to be considerable merit in further exploring the technical possibilities of conversion of sawdust to cellulosic products.

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Discussion

L. W. Mims (Cabot Carbon Company, Gainesville, Florida): 1. How is the commercial manufacture of Chlorine Dioxide handled? 2. Is specialized equipment required?

Dr. Levitin: Chlorine dioxide can be easily prepared by treating sodium chlorite with acid or chlorine. However since sodium chlorite is made from chlorine dioxide in the first place, and is very expensive, this method is only used where small amounts of CLO_2 are desired and the cost of setting up a chlorine dioxide generator is not warranted.

In large scale work CLO_2 may be prepared by several methods. The cost of the generators may run into several hundred thousand dollars. In all cases sodium chlorate is used as the starting product and the chlorine dioxide is absorbed in water.

The Holst process uses sulphur dioxide on acidified sodium chlorate solution. Rapson & Wayman of Hawkesbury, Ont., have a patent in which SO_2 is used on sodium chlorate without the use of any other acid. The Persson process uses SO_2 and acidified sodium chlorate with chromic sulphate as catalyst. I believe acidified sodium chlorate has been used with methanol to give CLO_2. Oxalic acid on sodium chlorate acidified with sulphuric acid may also be used.

However, recently a very fine process has been developed by Kesting in Munich, Germany, and I believe the Brown Corp. has the U. S. patent on the process. By this method sodium chlorate reacts with hydrochloric acid to give CLO_2, water, and sodium chloride. The sodium chloride is then converted back to chlorate in an electrolytic cell and the process continues. Thus CLO_2 really comes from HCl, HOH, and electric current, the sodium chlorate acting as a transmitter of oxygen. Kesting quoted that this process should make the cost of CLO_2 in the U. S. about 16¢/lb. With cheap electric current it should be even less. (This process at present looks very promising.) However, the cost of setting up the plant would probably be high.

Commercial Potentialities of Chemical Utilization of Wood

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Authors review various approaches to chemical utilization of wood, compare its value to lumber and fiberboards on a per ton basis, and suggest that economic justification for increased chemical utilization is at hand.

DUE TO THE ABUNDANCE of wood in our country we have grown to take its presence for granted. Seldom do we stop to consider its interesting complex structure which is so amazingly rich in chemical raw material. The uses for this great natural resource have been classified (reference 1) as falling into three avenues. These are: wood as wood; wood as fiber; and wood as chemical bodies. The objective of this paper is to appraise the commercial potentialities of chemical utilization of wood and show the logical reasons for optimism in visualizing its future.

The use of wood as a chemical raw material is old and has been carefully reviewed in recent publications (references 2 and 3). Examples include the manufacture of dissolving cellulose, wood sugar and products of wood distillation. Since much constructive effort has been spent on chemical utilization, the question naturally arises, "What do we have now which makes this avenue more attractive than it has been in the past?" To us the answer is indicated in complete integration of all three avenues of utilization combined with proper selection of processes within the chemical utilization avenue to the end that the yield of total products approaches complete utilization of the raw material.

The economy of any industry is vitally tied in with the cost of the raw material, processing costs, capital investment, yield of products, and market value of materials produced. In Fig. 1, is given the approximate sales realization which can be expected from each ton of wood (O.D. basis) which comes to the plant site, after it has been converted through each of the three avenues into marketable products. It will be noted that in general the selling price per ton of product in each instance is in approximately the same range, but that the sales realization from each ton of wood used varies because of the difference in yield of product. It also follows that since each of the established avenues is a commercially successful industry that the processing costs must be less in the cases where yield is low than in other cases.

Since sales realization per ton of wood varies directly with yield, profits should vary in a similar manner if manufacturing costs are held to a minimum.

In addition, this sales realization per ton of wood can be increased through integration of more than one avenue of utilization. To illustrate this, let us assume that fifty percent of a ton of barked log is converted into ninety-five dollar per ton lumber. This uses half of our raw material by a low cost conversion process. As a by-product from this conversion we have the other half ton of wood in the form of clean slabs, edgings, sawdust, shavings and perhaps decay. If these can be converted by a simple process with eighty-five per cent yield of chemicals at approximately the same selling price, the total yield is ninety-two and one-half percent and the realization per ton of wood is raised from forty-seven fifty to over eighty-seven dollars. Present practice includes utilization of a portion of these by-products, namely the clean slabs and edgings, for pulp, whole wood fibers, hardboards or particle boards. With the exception of a few mills converting shavings into particle boards or Presto-Logs, the other large volume by-products, which also include bark, find use primarily as fuel. We are offered, therefore, the opportunity of integrating into existing large mills a chemical utilization where a chemically rich raw material is available at plant site in a comminuted form for the price of fuel.

The chemical utilization of wood may be analyzed through the answers to three questions:

(1) Why consider the chemical approach?

(2) Are there commercial potentialities?

(3) If so, what are they?

It is logical that we should think of the chemical approach since we live in a chemical age where technological advances are rapid, and successful chemical enterprises are constantly called to our attention. Furthermore, we have a raw material that is abundant and available from a continually replenished supply in contrast to those oil, coal and mineral resources which are exhaustible. In addition, the chemical industry has established a good

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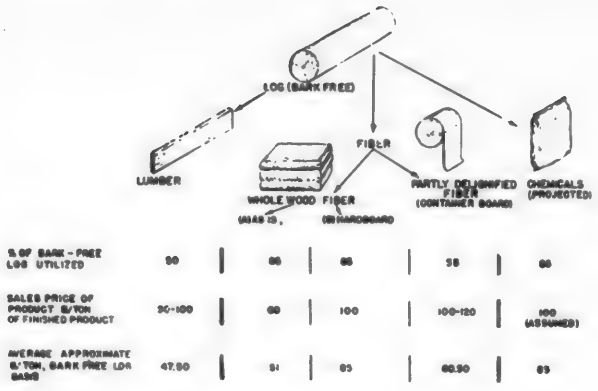

Figure 1.

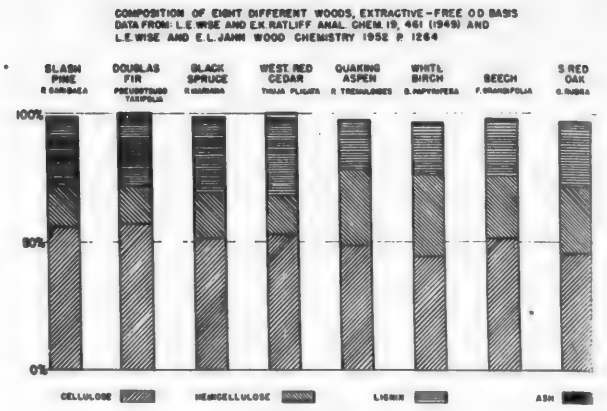

Figure 2.

earnings record and in general is considered a profitable one. Finally, by virtue of standardized plant equipment used for chemical processing, a certain leeway is permitted in the final products produced, giving an element of flexibility to cope with changing market conditions.

Before we can answer question two relative to commercial potentialities, we must consider several important factors:

(a) What is the nature of wood's composition?
(b) What is the structure of the building blocks in the components of this composition?
(c) Can these components or their building blocks be isolated?
(d) When such products are isolated, are they useful?

(a) A study of the composition of wood shows that it is an extremely heterogeneous material consisting of minor amounts of relatively simple organic compounds and a variety of polymeric materials. These polymers are of several types formed from different kinds of building blocks. In addition these polymers range in size from water soluble reactive units, containing relatively few building blocks, to very large polymers which are insoluble and resistant to chemical attack. Present day knowledge of wood's chemical characterization has been summed up in a one-sentence description (reference 6) as follows: "A skeleton of polysaccharide based fibers in which glucosan predominates, embedded and bonded in a polymerized aromatic matrix in which the phenyl propyl radical plays a major role as a building block, but accompanied by an aggregation of other organic compounds falling in neither category."

Broadly speaking, the components of wood fall into three classes: carbohydrates, lignins, and extraneous materials.

The *carbohydrate* part or holocellulose is essentially what chemists would call an ester-ether polymer. That is, the building units of this polymer are bridged by oxygen bonds of two types. In the main polymeric chain glycosidic linkages join simple sugar units which are predominantly glucose and xylose with lesser quantities of other sugars as mannose, galactose and arabinose. Attached to this chain by ester linkages are uronic acids of several sugars.

Lignin is a term used to describe a variety of products which have been produced from the binding material embedding the cellulosic polymers. Isolated lignins are polymers of unknown constitution formed from phenyl propane type building units. The number of these units in the polymer and the nature of their linkages and functional endings have not definitely been established. In situ, it may exist in a range of polymer sizes. In this form, it is a highly reactive material, possibly chemically bonded with the cellulosic polymers, and subject to varying degrees of modification during isolation.

Extraneous materials in the different woods vary widely in kind and quantity, excepting potash which is present in all woods in consistently small amounts. Other extraneous materials include, for instance, silica (bamboo, tropical woods), aromatic substances (eculayptus oil, camphor, rosin), protective substances (thujaplicin, quercetin, tannins), and alkaloids.

So far as the three classes of wood components are concerned, the relative proportions in woods of different types including tropical woods (reference 4) are quite similar. This is demonstrated in Fig. 2. Here it is shown that broadly speaking, woods of different types are identical, especially when comparing conifers of different species. However, when we study in detail the nature of the classes of components, variations are apparent. Examples of extreme differences are brought out when aspen and Douglas fir are compared. Whereas Douglas fir wood is difficult to separate into its components, aspen is readily broken down. The holocellulose content of aspen is much higher than Douglas fir, with a near normal cellulose content but much higher hemicellulose content. At the same time, the lignin in aspen which amounts to approximately nineteen percent of its composition is more easily removed than the approximately twenty-nine percent found in Douglas fir. Chemical analysis of the building blocks in the polymers shows some differences such as the presence of an additional methoxyl group in the lignin unit of deciduous woods.

(b) Since the chemical structure of these building units will control their chemical utilization, Slide III has been prepared to permit a clearer understanding of the two main types of units that make up the carbohydrate and lignin polymers.

At the top of the figure are the sugar units found in the carbohydrate polymers. Glucose is illustrated as a typical example. It has a ring structure containing five carbon atoms and one oxygen atom. This ring can be easily opened by mild chemical action, and the polymer units are readily separated at their glycosidic linkage by hydrolysis. On the other hand, the phenyl propane type of unit found in lignin polymers displays a different chemical structure. Here again, we have the presence of a six membered ring. However, this ring has an aromatic configuration which acts as a unit under mild chemical treatment and can be opened only by severe chemical action. Freudenberg has indicated that the linkage between the building blocks in lignin is of an ether type. This linkage is more difficult to cleave than the glycosidic linkages in cellulose.

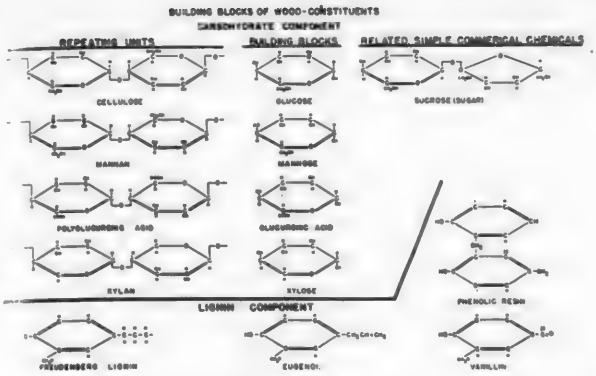

Figure 3.

TYPES OF PROCESSES USED IN CHEMICAL UTILIZATION OF WOOD

PROCESS TYPE	UNIT PROCESS	PRODUCTS
EXTRACTION	1. SOLVENT EXTRACTION	TANNINS ROSINS; TERPENES WAX DYES AROMATIC COMPOUNDS: CAMPHOR, PINE OIL,[a] EUCALYPTUS OIL[a] MEDICINALS: QUININE, CASCARA, QUERCETIN
FRACTIONATION	2. PREHYDROLYSIS	WOOD SUGARS MODIFIED LIGNOCELLULOSE
	3. TREATMENT WITH ALKALI	ALKALI LIGNINS CARBOHYDRATES OXY ACIDS
CLEAVAGE	4. DELIGNIFICATION	CHEMICAL CELLULOSE SUGARS SOLUBLE LIGNINS
	FOLLOWED BY OXIDATION	VANILLIN
	5. HYDROLYSIS	HYDROLYSIS LIGNIN LEVULINIC ACID REDUCING SUGARS
	4 AND 5 FOLLOWED BY FERMENTATION	ALCOHOL
	6. HYDROGENOLYSIS	PROPYLBENZENE
	7. PYROLYSIS	CHAR WOOD TAR GASES VOLATILE ACIDS (ACETIC)
	8. OXIDATION	OXALIC ACID PROTOCATECHUIC ACID GASES

[a] SOME OF THESE PRODUCTS ARE OBTAINED BY STEAM DISTILLATION

Figure 4.

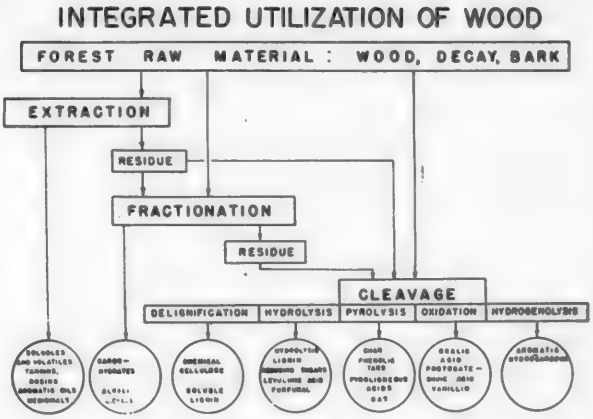

Figure 5.

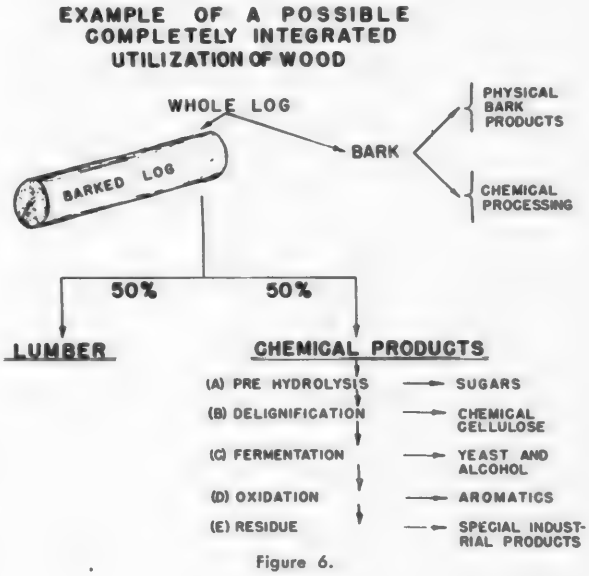

Figure 6.

(c) Recognizing the structure of the two main types of building blocks, their existence in polymeric form, and the fact that the two types of polymers are intimately mixed and possibly chemically bonded, we now consider the possibility of their isolation as building blocks or as polymers of various sizes. Here we must differentiate between isolating polymers of controlled size and cleaving the polymers down to the ultimate building block. In the first case, we merely rupture the bond between polymers and then break a few of the bridges in the large polymer to give the desired product. We know from long experience that once such a process is well started it is difficult to control and to stop at an intermediate level. However, technology has progressed to the point where this can be done in a few cases. During the production of chemical cellulose, the carbohydrate chains in wood with a degree of polymerization in excess of 4000 units are reduced to a range of approximately eight hundred to twelve hundred units. In the case of wood hydrolysis, the cleavage of polymers is carried down to the simple sugar level, and under the conditions of hydrolysis, part of the building block units are broken down into decomposition products as hydroxymethyl furfural and levulinic acid. This reaction,, however, can be controlled to give maximum yield of sugars, hydroxymethyl furfural or levulinic acid.

A great deal of effort and study has been given to the lignin portion of wood. A small part of the lignin as it exists in situ is believed to have been isolated in the laboratory and called native lignin. These relatively small polymers, due to their reactive nature, tend to condense under the conditions usually employed for their separation from the carbohydrate polymers so that most commercial lignins are comparatively large polymers. Such polymers can be broken into modified building units through chemical action, such as the production of vanillin by oxidation of lignin sulfonic acids.

(d) The usefulness of the products that can be isolated has been only partially established. A million tons of chemical cellulose is used annually in the production of cellulose derivatives. Wood sugar from hydrolysis must compete with blackstrap molasses which enjoys a free market from sugar crops produced all over the world. In order for this to be economically sound, the other products of the hydrolysis must find profitable utility. At present, no one has been able to do this with the condensed lignin formed during hydrolysis. Hydroxymethyl furfural and levulinic acid are well known organic chemicals and there can be little doubt that markets can be devel-

oped for them if they can be produced and sold at attractive prices.

The utility of lignin components falls into two fields: those relating to use of a polymeric material and those directed towards using the building unit. Several companies have made excellent progress in the field of marketing modified recovered lignin polymers, but at present only a small portion of the available raw material is used. The second approach offers a tremendous potential. This aromatic building unit could be a basic raw material for enormous chemical markets now being supplied from coal tar, oil and gas resources. A process which produces cheap aromatic neuclei has ample markets in which it can expand. A step in this direction is the current commercial production of vanillin by oxidation of waste liquor lignins.

Let us now turn to consideration of what might constitute a commercial process for complete chemical utilization of wood. In so doing, we must evaluate the following:

(a) Available processes and resulting products.
(b) Possibility of integrating such processes.
(c) Ability of selected process to meet the conditions required for successful commercialization.

(a) The various processes that have been established to utilize wood chemically can be grouped into three types, namely: extraction, fractionation and cleavage. These may be defined as follows: *Extraction* is the removal of certain constituents of the wood in an unchanged condition by putting them into solution through simple solvent action of water or organic solvents; or by steam distillation. *Fractionation* is the breaking down of wood into fractions through stepwise application of chemical action limited in intensity during each step to the minimum severity required to remove and isolate the fraction, (reference 5). Products are obtained with some modification but ideally tend to retain their original structure. *Cleavage* accomplishes the collapse of wood structure through a single vigorous physical or chemical means forming modified building units or their decomposition products.

In Fig. 4 some of the processes falling in these three types have been listed with the products formed in each case. In general, these processes, with the exception of the production of chemical cellulose, do not represent large chemical industries, and the main reason for this condition lies in the low yield of products produced. Successful processing continues primarily in those instances where a very rich natural extractive (for example, Quebracho) occurs and its market price will carry the industry even though yield is low from the standpoint of total utilization of the wood; or in those cases where an otherwise valueless or nuisance by-product is converted into a valuable product and the return as a limited yield is sufficient to justify the processing costs.

If the processes listed in Fig. 4, or modifications of them, could be applied to the raw material in a preferred sequence of operations so that as an integrated result a high total yield of products were obtained, the economics could be vastly improved.

A schematic indication of the possibilities of integration is given in Fig. 5. In studying this figure, it is soon apparent that a great variety of combinations of steps is possible. The fundamental approach is a gradual increase in severity of treatment with removal of sensitive products as they are produced to prevent their cleavage or condensation by subsequent treatments used for further breakdown of the raw material.

Before carrying this approach farther, we should analyse the conditions which must be fulfilled to usefully employ a chemical raw material. As pointed out in reference 6, there are three broad requirements; namely, adequate technology, sound economics and proper timing. The technology must cover all of the scientific understanding of the nature of the raw material as necessary to develop the process to obtain the most valuable products possible in the highest yield. The decline of the wood distillation industry is an example of inadequate technology, and lack of integration, combined with low value products so that the economics became unsound when the synthetics became available. Sound economics require that when price is in line with utility, a suitable profit margin exists above costs. Proper timing involves the urge for action. This may come from such factors as a shortage of supply of other materials, a shortage of raw materials, an abnormal price situation or artificial conditions such as brought about by a war. The semi-chemical pulp industry illustrates this point. The first mill runs were made by the Forest Products Laboratory as early as 1929, but no appreciable progress was made in the industry until after World War II when the greatly increased demand for corrugating board provided the urge to use the process.

The chemical utilization of wood will be on a sound economical basis when all of the following requirements are met:

(a) A low cost raw material must be used. This is now available under favorable conditions through integration with other processes. The portions best used for lumber or fiber are processed for those products thereby making available low value sawdust, decay and barker waste for chemical production.

(b) Chemical processes must be integrated to give diversified products. Some indications of how this may be done have been given. An example of how proven processes might be tied into one plant is illustrated in Fig. 6. Additional research will develop other improved combinations.

(c) The chemical processes chosen must be simple and reliable, using low capital investment and minimum labor. This is the first hurdle to be met and is more favorable under extraction and fractionation conditions than for cleavage.

(d) The products produced must be of high utility and, hence, command a fair price. This has been accomplished in chemical cellulose and vanillin. It would be true for ethanol if the by-products were made to carry their share of the realization. It has been shown that other valuable chemicals are potentially available.

(e) The products produced must be suitable for large volume broad markets. Some of these are proven while others are not.

The problems confronting chemical utilization have been set forth. Some of them are technical, while others are economic, none are insurmountable. By and large they present a favorable picture.

In conclusion, we feel that the future of chemical utilization of wood is not only possible but is inevitable. With continued improvement in technology, with complete integration for improved economics and with increased world demand for the valuable chemicals potentially available, the right timing will soon be at hand

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5. U. S. Patent 2,541,058, Canadian Patent 469,638–9.
6. J. L. McCarthy, C. C. Heritage, "What is Wood, As a Chemical Raw Material," paper presented at Technical Section Symposium, CPPA, Montreal, Canada, January, 1953.

Discussion

R. R. Bottoms (National Cylinder Gas Co., Crestwood, Ky.): Do you include bark in your utilization program?

Dr. Esterer: Yes, we do, but there are complications. The composition of bark is very different from that of wood. Therefore, it is recommended to separate bark from wood mechanically before subjecting either to chemical separation processes. Without mechanical separation of bark, yield calculations become difficult since bark content of the rough log varies with tree species from almost zero in Eucalyptus to as much as 12 percent for Douglas Fir, and changes substantially depend on log age, size and position in the tree.

W. J. Tomford (James E. Stark Company, Memphis, Tenn.): Are all logs debarked at the Weyerhaeuser Timber Company operations?

Dr. Esterer: Practically all logs are debarked at all of our mills except at one small mill.

George Rives (Poinsett Lumber Company, _____): You made reference to the chemical utilization of bark and decayed wood. Is this commercially feasible and how much can you use? Is the cost of transportation of this material a limiting factor?

Dr. Esterer: The chemical utilization of bark appears to be commercially feasible. Decayed wood is not in the same category. Decay is a suitable material technically for chemical utilization, but there are collection and transportation problems especially for advanced stages of decay which separate from the log during handling before logs reach the mill.

Mr. Sproull: We frequently speak of lignin and cellulose together. Do you think that they are chemically bound in the wood or are they present as separate units?

Dr. Esterer: This is still considered an unsolved problem. It is my personal opinion that there is very definitely a bond between carbohydrates and lignin rather than between cellulose and lignin. A great deal of detailed work has been done in this field. We should take a more general view of the problem. Lignocellulose acts as if it were a compound consisting of carbohydrates and mono or polyphenols, the bond between them being easily broken in chemical reactions. There is physical and chemical evidence for this. Swelling agents can swell a sheet of isolated cellulose to nine times its thickness whereas under the same conditions we obtain very little swelling of cellulose in the matrix of lignocellulose. If we treat lignocellulose with an alkali, the phenols are rapidly cleared off and oxidized to a brown product, alkali lignin, which generally resembles products obtained by the action of alkali on polyhydric phenols, such as pyrogallol. If we try to break the bond in lignocellulose with an acid, the effect is cleavage by hydrolysis, and subsequent polymerization of phenols to insoluble products.

The problem is, therefore, to ascertain the nature of the bond between carbohydrates and phenols and to find a way to break it that will permit the use of the components. The present methods of cleavage are too severe, and should be replaced by milder methods.

Mr. Sproull: I understand that the ideal process is to start with a gentle treatment and gradually increase the severity. To what extent is this possible now?

Dr. Esterer: Great strides have been made in this direction and I believe we can see our way as shown in slide 5.

G. G. Sward (National Paint, Varnish & Lacquer Association, Washington, D. C.): You spoke of decay. Is decayed wood a product or a raw material? Do you promote it as a raw material for, say, biologicals?

Dr. Esterer: Yes, we consider it as a raw material. It has been mentioned in the patent literature as a binding material for fibers and it has been recommended, a few years ago, to produce such decay artificially but no progress seems to have been made. I believe that so far decayed wood is not being used as a raw material for the production of biochemicals. From the standpoint of lumber manufacture, the presence in limited amounts of certain kinds of decay as that caused by Fomes Pini, enhances the decorative effect obtainable. One such product for interior finish is called driftwood. A certain amount of decay is accepted in some grades of lumber.

TECHNICAL SESSION IV—Tue., June 16, 1953, 9:00 A.M.

Subject: Containers and Protective Packing Materials

Chairman: Earl R. Stivers

Recorder: David E. Herrick

Basic Design Data for Solid Fiberboard Shipping Containers[1]

K. Q. KELLICUTT
Engineer

and

E. F. LANDT
Technologist, Forest Products Laboratory,[2] Forest Service, U. S. Department of Agriculture

Paper discusses the use of a formula for predicting the top-to-bottom compressive strength of solid fiberboard boxes as well as a means of interpreting the strength values for various moisture contents of the fiberboard and a means of determining stacking loads for boxes in storage. It also discusses the box strength calculator, which simplifies the use of design data for both solid and corrugated boxes.

Introduction

NUTS, BOLTS, STOVES, refrigerators, washing machines, furniture, food, clothing, and literally thousands of articles today are packaged, shipped, stored, displayed, and sold in fiberboard containers. New uses are continually being made of fiberboard and have accounted for the phenomenal growth of the industry in the past 50 years. In recent years the growth has been especially significant to the South where paperboard and fiberboard box manufacturers have expanded their facilities.

Because of this rapid growth, research has lagged developments in this field. Although much has been done in the way of basic studies of fiberboard for shipping containers, and much information has been accumulated (*5, 6*)[3] as a result of experience on the performance of fiber containers, more work needs to be done. Better and cheaper methods need to be developed for making fiberboard water resistant. This would provide many new uses for fiberboard. Also, more meaningful specifications for fiberboard boxes need to be developed.

Recognizing the need for design criteria for use of fiberboard in shipping containers, the Quartermaster Food and Container Institute for the Armed Forces has collaborated for several years with the Forest Products Laboratory on basic research involving the strength properties of the component paperboard sheets, the built-up board, and the finished fiberboard box.

The work has been undertaken in two phases. The first phase, development of design criteria for corrugated shipping containers, is partially completed (*7, 8, 9, 10*). The second phase, which primarily involves solid fiberboard, has been started. This paper will present some of the work that has been done in the second phase of the work.

Since similar materials are used in corrugated fiberboard and solid fiberboard, and since many of the relationships that were established for corrugated fiberboard boxes also apply to solid fiberboard boxes, the first logical step is to summarize the work that has been done on corrugated fiberboard.

Phase I—Background Information

Early studies at the Forest Products Laboratory showed that the strength properties of the component paperboard sheets could be correlated with those of the built-up board (*1, 2, 3, 4*). However, the early studies, which involved the evaluation of paperboard and corrugated fiberboard, made use of testing techniques that were considered too exacting and precise for general use (*1*). Simple testing techniques were needed before the use of design criteria could be made practical. Therefore, when the work was resumed after World War II (the study was inactive during the war), the primary objective was to develop simple testing techniques (*7, 9*). Several techniques were tried and evaluated. The most promising component tests were found to be the ring-crush test and strip-column test.

Formulas were evolved (*7*) in which the test values obtained with either the ring-crush or strip-column test of paperboard sheets could be used to predict the compressive strength of corrugated boxes. When the same testing techniques were tried with the components of solid fiberboard, the strip-column test was found to be the most applicable. The heavier strips of paperboard used in making solid fiberboard, especially the filler sheets, often checked or cracked when they were formed into the circular ring-crush specimen holder. This did not occur when the strips were held straight between two edge clamps in the strip-column test.

Development of a Design Formula for Corrugated Fiberboard Boxes: The work that had been done at For-

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[1] This paper reports research undertaken in cooperation with the Quartermaster Food and Container Institute for the Armed Forces and has been assigned No. 419 in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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ABOUT THE AUTHOR: LANDT, EUGENE F. Received BS degree in forestry from Montana State University School of Forestry, Missoula, Montana, where he studied logging engineering and forest management. Spent three years on active duty in the Navy during World War II with rank of lieutenant. Has been at the USFPL since 1947. Member: Society of Amer. Forests and Wis. Chap. of Sigma Xi.

[3] Italic figures refer to articles listed in the Literature Cited.

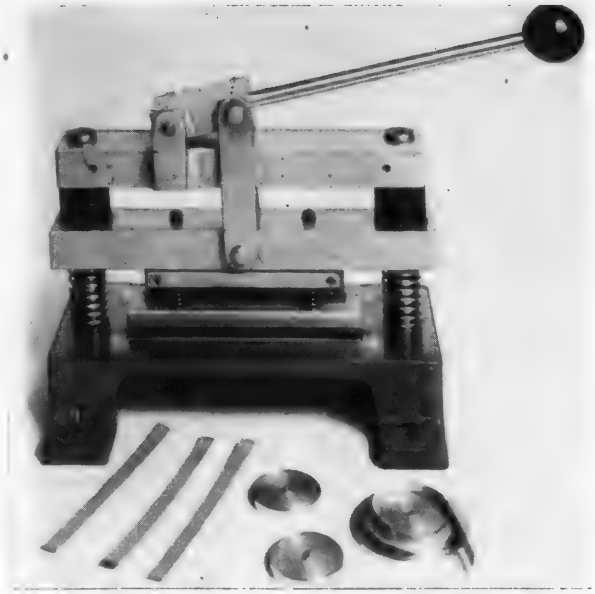

Figure 1.—Specimen cutter used to prepare test strips of paperboard for ring-crush test. Sample strips and a ring-crush specimen holder are shown in the foreground.

Figure 2.—A paperboard strip, together with one properly inserted in the edge clamps used for strip-column test.

est Products Laboratory on applying the thin plate theory of mechanics to design of plywood (*11, 12, 13, 14*) provided a basis for a design formula for corrugated fiberboard and later for solid fiberboard. The theory could be applied because both of these materials are like plywood in that they are nonisotropic. From the plywood formulas, a basic design formula was evolved for corrugated board. This basic formula was modified and simplified several times and resulted in the following formula for predicting the top-to-bottom compressive strength of A-, B-, and C-flute boxes when the flutes are vertical in the side walls:

$$P = P_x \left(\frac{a_{x_2}^2}{\left(\frac{Z}{4} \right)^2} \right)^{1/3} ZJ$$

in which

P = total compressive strength of box in pounds

P_x = composite ring-crush load of built-up board (pounds per inch)
(P_{r1} single face + P_{r1} double back + $\propto x P_{rc}$)

P_{r1} = ring-crush load in pounds per inch of a ½- by 6-inch strip of liner either in the with- or across-machine direction, dependent upon P

P_{rc} = ring-crush load in pounds per inch of a ½- by 6-inch strip of corrugating medium in the across-machine direction

$\propto$ = ratio of length of corrugating medium when flat to its length when corrugated (A-flute = 1.523, B-flute = 1.361, C-flute = 1.477)

a_{x_2} = either 8.36, 5.00, or 6.10 for A-, B-, or C-flute, respectively

Z = perimeter of box in inches

J = box factor for the appropriate kind of fiberboard
A-flute = 0.59
B-flute = .68
C-flute = .68

To simplify the use of the formula, alinement charts were constructed for A-, B-, and C-flute boxes (*7*).

To further simplify the use of the data, a box strength calculator was developed (*10*). The calculator, which consists of five circular disks with various scales and indexes with a hair-line indicator, can be used to solve design problems by simple manipulations of the disks of the calculator. It incorporates design data for corrugated fiberboard as well as some of the information that has been accumulated for solid fiberboard.

Phase II—Solid Fiberboard

Several forms of material and test methods are being used to develop design criteria for solid fiberboard boxes. Component paperboard tests are made with the strip-column technique; structures, such as tubes (a box without top and bottom), and boxes are being tested in compression, and some dead-load tests are being made with boxes. The tests are being conducted in various atmospheres so that the effect of moisture content of the fiberboard on compressive strength can be determined.

Strip-column Test: The strip-column test was used to test components of the solid fiberboard. The test specimens were of the same size and cut with the same specimen cutter used for preparing the ring-crush test specimens (fig. 1). The cut specimens, ½ by 6 inches, were held straight between two clamp supports (fig. 2) so as to provide a column of paperboard ⅛-inch high above the clamps. The column was crushed in a testing machine where only a single value, that of maximum load, was obtained. Specimens were prepared so that both the with-machine and across-machine directions of the paperboard components could be tested. The tests were conducted in a room maintained at 75° F. and 64 percent relative humidity.

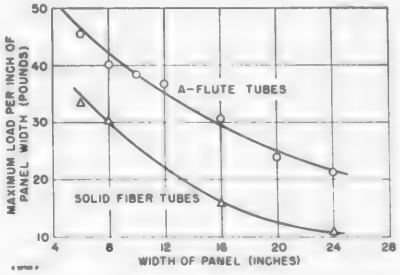

Figure 3.—Typical buckling curves for cubical A-flute corrugated tubes and cubical solid fiberboard tubes in sizes ranging from 6 to 24 inches.

Table 1—MAXIMUM STRIP-COLUMN CRUSH VALUES OF TYPICAL LINERS AND PAPERBOARD FILLER STOCK

Material and description	Basis weight Lb./1,000 sq. ft.	With-machine direction Lb./in.	Across-machine direction Lb./in.
Liners			
1. Fourdrinier kraft	42	15.9	9.8
2. Fourdrinier kraft	54	17.4	12.6
3. Jute	85	29.8	16.1
Filler			
1. Plain chip	100	18.3	11.0
2. Plain chip	118	23.6	14.1
3. Plain chip	137	28.6	17.4

The with-machine values were as much as 1.85 times as great as the across-machine values for the various liner boards tested. For the filler sheets, the values for the with-machine direction were as much as 1.67 times as great as the across-machine direction. Typical values resulting from the strip-column test for some liner boards, as well as for some of the filler sheets, are shown in table 1.

Relation of Strip-column Values to Built-up Board: It was found that the single strip-column values of the component sheets could be added to provide a composite value for the built-up board. Although these composite values were lower in most instances, they correlated well with the actual crushing loads attained for samples of the built-up board. The higher values attained for the built-up board can be accounted for by the additional stiffness resulting from the adhesive used on the components of the built-up board. Also, the inner sheets of the board are restrained by the outer sheets and attain higher crushing and buckling values than when tested without support. The tests of the built-up board consisted of strips ½ by 3 inches supported in the same edge clamps that were used for the strip column and arranged to provide a free column of ⅛ inch above the clamp. Test values for the built-up board, individual values for the component paperboard sheets, and composite values obtained by adding the component values are shown in table 2.

After this relationship between tests of the components and tests of the built-up board was established, it became apparent that the same general scheme could be used to calculate the compressive strength of a structure fabricated from the built-up board as had been developed for corrugated board, provided the relationships that had been established for corrugated board, involving size and shape of cross section and height of the tube, were the same.

Compression Tests of Solid Fiberboard Cubical Tubes: Top-to-bottom compression tests were made on cubical tubes fabricated in the Laboratory from sheet stock obtained from several commercial box plants. The tests included sizes of 4-, 6-, 8-, 12-, 16-, and 24-inch cubical tubes with the machine direction of the paperboard either parallel or perpendicular to the applied load. The results of these tests on solid fiberboard tubes revealed that the same relationships between load and size did exist that had been found for corrugated board in previous studies. The buckling curve for cubical corrugated tubes and a similar curve for cubical solid fiberboard tubes are shown in figure 3. Although the curves converge slightly for the small sizes, they are generally the same shape and slope. The slope of the curve for solid fiberboard tubes was found to be one-third, the same as had been previously calculated for corrugated tubes. Therefore, the same general formula, with slight modification, could be used for calculating the top-to-bottom compressive strength of the solid fiberboard tubes and boxes.

Modification of Formula to Apply to Solid Fiberboard: The formula was modified by including a factor representing the grain direction of the fiberboard with respect to the applied load and a box factor in the formula for P. By comparing actual tube and box loads, the box factor was found to be 0.70. By using values from the strip-column test rather than the ring-crush test for the determination of P_x quantities, good correlation was found between actual top-to-bottom compressive test loads and calculated loads for solid fiberboard boxes (table 3).

Development of Duration-of-load Information for Solid Fiberboard Boxes: It had been known that fiberboard boxes cannot be expected to support a stacking load equivalent to the load attained by a compression test of a box in a testing machine. In previous tests of corrugated boxes it was found that dead loads that approached the static compressive strength of the box caused failures usually within minutes (*8*), while dead loads of about 60 percent of the compressive strength caused failure in about month. From tests of many corrugated boxes, conditioned in various atmospheres, the relationship between the machine test load, dead load of storage, and the duration of load was established (fig. 4).

Using the relationship thus established, duration-of-load tests were made with solid fiberboard boxes, and the failures were found to follow the same trends (table 4).

As it had been calculated that a load representing 50 percent of the machine test value of a box would cause failure in about 300 days, a long duration test was started with a solid fiberboard box made of W5s board. The machine test load attained for similar boxes was 558 pounds. Hence, a load of 279 pounds (50 percent) was placed on the box September 25, 1952. At the end of March 1953, 187 days had elapsed and it appeared that the box would sustain the load for the calculated 300 days.

These tests indicate that the curve shown in figure 4 may be used to determine the amount of dead load a box can be expected to sustain for specific periods of time. However, these tests were conducted with boxes that had not been previously rough handled and were not damaged. Rough handling prior to storage will reduce the compressive strength of the box and consequently will reduce the duration for a specific load.

Duration-of-load Data Applied to Boxes in Actual Storage Conditions: The duration-of-load information was recently applied to boxes in storage in military supply depots. A survey of three eastern supply depots showed that, without exception, when the actual load on the boxes in stacks exceeded the load the boxes could be expected to withstand (based on calculated compressive strength values and a specific dead load for a definite duration), failures had resulted. Conversely, when the dead loads were within the reasonable limits of the

Table 2—TEST VALUES FOR A BUILT-UP BOARD AND COMPONENT SHEETS

Material and description	Edgewise crush test of components		Edgewise crush test of built-up board	
	With Lb./in.	Across Lb./in.	With Lb./in.	Across Lb./in.
Liners				
1. Fourdrinier kraft	15.9	9.8	----	----
2. Fourdrinier kraft	15.3	10.1	----	----
Fillers				
1. Plain chip	22.9	15.3	----	----
2. Plain chip	28.5	15.9	----	----
Total values	82.6	51.1	98.0	68.0

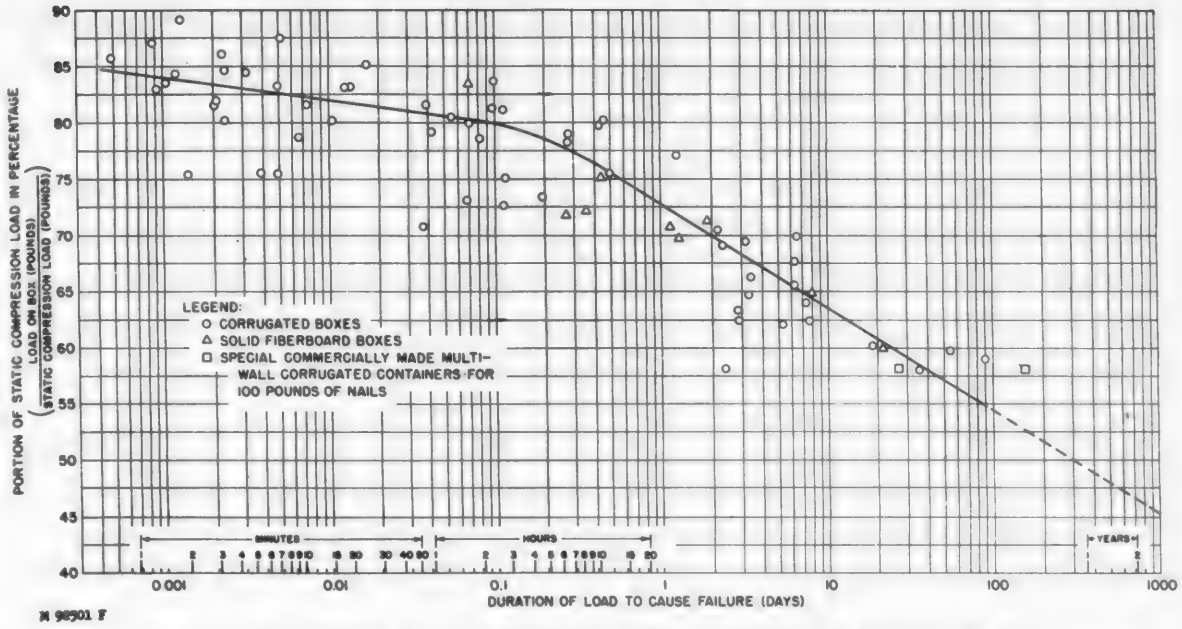
PORTION OF STATIC COMPRESSION LOAD IN PERCENTAGE (LOAD ON BOX (POUNDS) / STATIC COMPRESSION LOAD (POUNDS))
LEGEND:
CORRUGATED BOXES
SOLID FIBERBOARD BOXES
SPECIAL COMMERCIALLY MADE MULTI-WALL CORRUGATED CONTAINERS FOR 100 POUNDS OF NAILS
MINUTES
HOURS
YEARS
DURATION OF LOAD TO CAUSE FAILURE (DAYS)
M 98501 F

Figure 4.—The relationship of the compressive strength of a box (machine test load) and the dead load that will cause failure in specific durations.

data, the stacks were standing and no failures were apparent or imminent.

In the early part of the investigations, slight changes in the moisture content of the boxes during a test were found to reduce the duration, and it became apparent that the moisture content of a box could be related to its compressive strength.

Relation of Moisture Content of Fiberboard to Compressive Strength: From tests of the compressive strength of various boxes in several different atmospheres in conjunction with the duration-of-load study, it was found that the relationship between compressive strength of the box and moisture content of the fiberboard could be expressed by a formula (7). This formula provides a convenient means of finding the compressive strength of a box at any moisture content when its compressive strength is known for a specific moisture content. To make it easier to interpret the information, an alinement chart was constructed (fig. 5).

This chart was first used for corrugated boxes, but was found to apply to boxes made from solid fiberboard, as can be seen by comparing the actual test values with the calculated loads, determined with the chart, shown in table 5.

Table 3—SOME TYPICAL CALCULATED AND ACTUAL TEST LOADS FOR SOLID FIBERBOARD BOXES

Lot No.	Components	Basis weight Lb./1,000 sq. ft.	Size of box Length, Width, Depth Inches	Top-to-bottom compressive strength of box: Actual test Lb.	Top-to-bottom compressive strength of box: Calculated value Lb.
2S	Fourdrinier kraft liners Chip fillers	279	16¾ x 12 x 5	830	795
6S	Fourdrinier kraft liners Sized chip fillers	332	16¾ x 12 x 5	1,538	1,560
7SC	Fourdrinier kraft liners Chip fillers	200	18½ x 7 1/8 x 8 7/8	448	431
10SB	Jute laminated liners Chip fillers	375	16⅝ x 12¼ x 9 3/8	990	1,100
13S	Jute liners Chip fillers	345	12¾ x 8 3/4 x 8½	835	805

Table 4—RESULTS OF DURATION-OF-LOAD TESTS OF SOME SOLID FIBERBOARD BOXES AT VARIOUS DEAD LOADS

Static compressive strength of comparable box	Actual dead load on box Pounds	Ratio of dead load to static compressive strength Percent	Time to failure Days
48	340	70	1.35
47	340	72	.25
54	355	65	7.88
52	310	59	28.70

Uses for the Data: The data developed as a result of the basic study of fiberboard, both corrugated and solid, will serve several purposes.

First, it will provide a basis for charts and tables for use in preparing general specifications for various kinds of fiber boxes.

Secondly, having been applied in the Laboratory to commercially made boxes, the information will provide a means of checking quality control operations in commercial box manufacturing plants. To simplify calculations, the data have been incorporated into a box strength calculator (*10*) (fig. 6). With the calculator, the top-to-bottom compressive strength may be determined for any size box with various combinations of components fabricated into either corrugated or solid fiberboard. Also, the stacking loads for specific durations can be determined, as well as the compressive strength values for various moisture content values of the fiberboard.

These studies should also stimulate further basic research on fiberboard boxes and extend their use.

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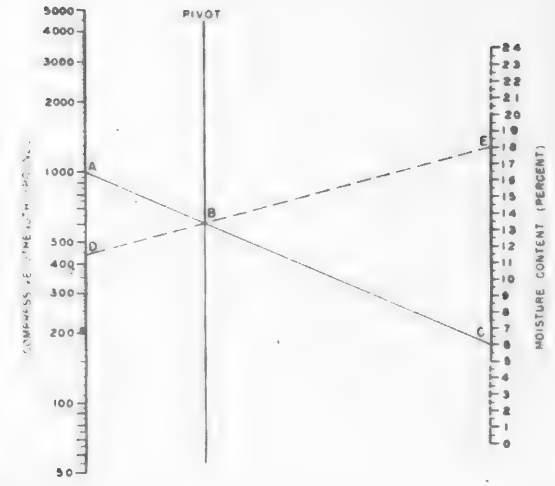

Figure 5.—The relationship of the moisture content of fiberboard and compressive strength of the box may be determined when the strength is known for one moisture content. Here it may be seen that a box having a compressive strength of 1,000 pounds at 6 percent has a compressive strength of less than 450 pounds when the moisture content is increased to 18 percent.

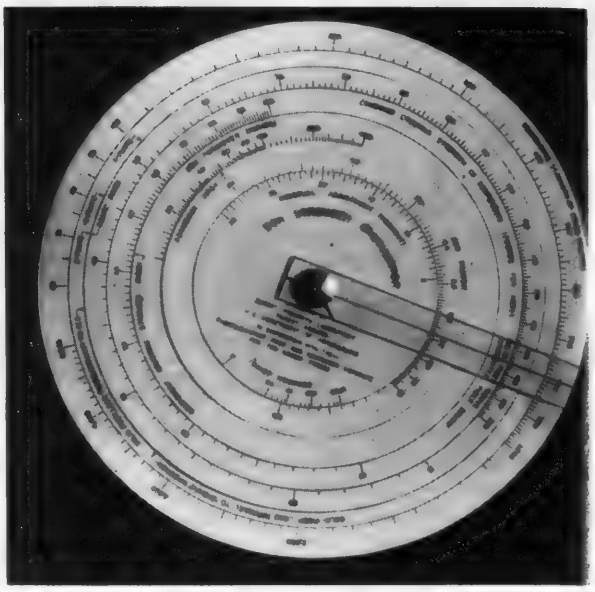

Figure 6.—This box strength calculator provides an easy means of determining top-to-bottom compressive strength of corrugated and solid fiberboard boxes. The influence of moisture content of the fiberboard and duration of load may also be determined by simple manipulations.

Table 5—ACTUAL COMPRESSIVE STRENGTH COMPARED TO CALCULATED COMPRESSIVE STRENGTH OF SOLID FIBERBOARD BOXES AT VARIOUS MOISTURE CONTENT VALUES. BASED ON ORIGINAL COMPRESSIVE STRENGTH OF 786 POUNDS AT A MOISTURE CONTENT OF 9.0 PERCENT

Box No.	Actual		Calculated compressive strength Pounds
	Moisture content Percent	Compressive strength Pounds	
1	6.32	865	940
2	12.49	651	615
3	18.29	389	410
4	25.83	261	242

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Discussion

O. T. Sands (Sears Roebuck and Company, Chicago, Illinois): What is the greatest limiting factor in the use of fiberboard boxes?

Mr. Kellicutt: The relatively low wet-strength of fiberboard. Better and cheaper methods need to be developed to make fiberboard water resistant.

J. F. Beckman (Signode Steel Strapping Company, New Orleans, Louisiana): What part, if any, did steel strapping play in this study?

Mr. Kellicutt: The influence of strapping has not been incorporated into this study as yet.

Mr. Sands: What factors in fabrication are responsible for panel warpage in corrugated fiberboard?

Mr. Kellicutt: Panel warpage is usually traceable to unbalanced construction or unbalanced moisture conditions in the board.

Mr. J. A. Watkins (Watkins Patents, Inc., New Haven, Connecticut): You mentioned the difference in values obtained in the strip-column and ring-crush tests between the with-machine and the across-machine spec-

(Continued on page 224)

Research and Design in the Packaging Field

JOHN M. LADD

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Importance of research in the packaging field is stressed by the fact that between 15–20 percent of the total production of lumber is used for boxing and crating—much of it in the lower grades otherwise difficult to market. In addition, approximately 25 percent of the total paper production is used by the packaging industry. Crux of the packaging research problem is proper protection at the lowest possible cost.

THE SCOPE OF THE FIELD covered by the terms "Packaging and Packing" is tremendous, and the research problems connected with this industry are equally broad. The industry naturally includes manufacturers of containers of all types: nailed wood boxes, plywood boxes, wirebound boxes, corrugated cartons, metal drums, bags, tubes, bottles, and many others, each with countless variations. In addition, tapes, glues, preservatives, desiccants, cushioning materials, plastics, vapor barriers, etc., are all important in the packaging field and must be considered.

A check of listings in a Packing and Shipping Directory revealed over 500 different types of listings for manufacturers of products all connected with the packaging field. Nearly everyone of the many companies in each of these branches of the business has an active research department trying to improve its existing products and to develop new ones. Government, commercial, and Association laboratories are likewise active. Thus, the accumulated research data in the field would fill volumes, much of which would be outdated before leaving the printers establishment.

There is, however, one basic objective behind all this research, which, simply stated, is merely to produce containers or shipping methods which will carry products to their destination safely at lowest possible cost. Since different products require different characteristics in containers, much of the research can be classified more accurately as package design for specific items. In this phase of research, certain tenets are applicable regardless of the type of container, a fact that will be stressed in a discussion of container design in relation to the packaging engineer.

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Examples

The manufacture of shipping containers is not new and there are seldom any sensational or revolutionary developments to report. Most research is necessarily devoted to improvements of detail or the adaptation of known principles to new uses. However, notable improvements can be brought about by research in packaging, as shown by the contrast in methods of preservation used on many items of government material in the first World War, the second World War, and at the present time. During the first war, items were either left unprotected or coated and filled with grease, which was fairly effective but extremely difficult to remove in the field. During the last war, many excellent preservatives were developed. With specialization in mind, the nature of the product dictated the type of treatment received. One of these treatments left films of varying degrees of hardness on the item, and in turn required protection by various types of moisture-proof and grease-proof papers. Another method employed strippable plastic coverings applied by dipping. More complicated items required the use of vapor barriers in conjunction with desiccants in order to keep all moisture from the product in the so-called Method 2 pack.

Application of these methods in World War 2 soon brought to a minimum the terrific loss of material through corrosion, which had previously been experienced by the armed forces in exporting their stocks of supplies. Today many additional products are available, such as moldable aluminum foil and improved plastics. An entirely different method employs volatile corrosion inhibitors, with no preservatives being used on the product itself. Protection is secured through the release of vapor from a chemically treated paper in which the item is wrapped or with which the shipping container is lined.

An example of current research not yet completed is the study of aluminum foil lined boxes for shipment of citrus fruits. It shows promise of reducing spoilage and of increasing storage possibilities and merits continued study.

A still different type of development, recently publicized by the North Atlantic Lobster Institute, is the use of a dry refrigerant which supplements a specialized container. It shows promise of improving lobster distribution to distant areas. A small quantity of water ice is added to some of the new dry refrigerant within a waterproof, heat-sealable bag. The bag is placed on top of the live lobsters in a special corrugated container which is aluminum foil coated on the outside and has aluminium foil coated insulation on the inside. The interaction of ice and chemical in the waterproof bag produces and maintains satisfactory conditions inside the container for up to 44 hours.

Another new product currently being discussed is that of "Tear Strip Cartons" in which a narrow strip of filament tape is attached to fibreboard carton blanks, permitting opening of the carton similar to a package of life savers.

Imagination Important

Our own company experimented for years to develop a satisfactory wirebound tobacco hogshead. Success was finally achieved and hundreds of thousands of them have been sold. One of

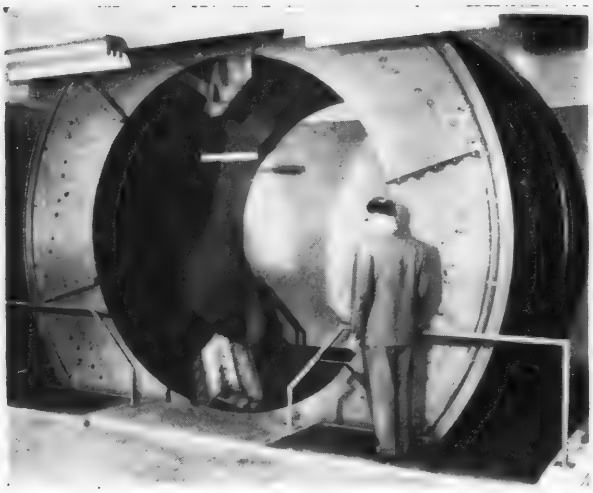


Figure 1.—Revolving drum subjects all parts of container to impact and is means of comparing different types of containers under same load.

Figure 2.—Incline-Impact testing device similates humping of freight cars and general rough handling.

the interesting parts of the story was the work on the type of closure in which even zippers were tried on this wood container, which must hold 1,000 pounds of tobacco packed under terrific pressure. Thus imagination is as vital to research in packaging as in any other field.

The Consolidated Freight Classification now lists over 1,000 special packages in addition to the general specifications for standard type containers. Each of these was developed, through research and tests, for specific items. Since many similar principles were considered in each case by the packaging engineer concerned, these principles are worthy of discussion here.

Package Design

The design of shipping containers is not as precise a science as that of bridge engineering or building design, but there are many parallels. Packaging engineers, like architects, are concerned with physics formulas, with stress, strain, vibration frequencies and amplitude, and impact forces. The work can be extremely technical, but it should be quickly added that, although there are many technical aspects to consider in package design, common sense, plus years of practical experience, are equally important. There are no startling principles of packaging engineering which can be quickly given out to make experts of the beginners—a point which can best be illustrated by a discussion of the many things which an industrial packaging laboratory will consider and do when designing a shipping container for a specific item.

Preliminary Design Factors

The initial consideration revolves about four factors of prime importance in package design, which could be listed as follows:

1. Adequate product protection.
2. Compliance with applicable specifications.
3. Cost.
4. Conformance with handling requirements.

These broad divisions may be discussed in detail to illustrate the work of the packaging laboratory and packaging engineer.

Package Testing

It goes without saying that a package should be sufficiently strong and of proper design to carry its product through normal transportation hazards and deliver it to destination without damage. Each shipper certainly desires this and intends to so pack his products. Yet the railroads alone pay out over 100 million dollars annually in damage claims, much of which is a direct result of faulty packaging. Adequacy of the container can be checked either by shipping tests or by preshipment tests conducted in a laboratory. Extensive shipping tests are most conclusive, but because they are expensive and time-consuming, and may possibly result in much damaged merchandise before faults can be corrected, many engineers work with laboratory tests. They may use drop tests wherein controlled falls are given to corners, edges, or faces of the container from varying heights. They may use tests in which the package is subjected to rough treatment in the revolving drum illustrated in Figure 1. In this machine, scientifically placed hazards will assure that all segments of the container are subjected to impact. This is an excellent method of comparing the protection offered by two different types of containers when tested with the same load.

Another important method of testing makes use of the Incline-Impact Testing Device, illustrated in Figure 2. In this test, the package is placed on a dolly which runs down a track inclined at 10° until it strikes a solid barrier. Both faces and edges of the container may be subjected to these impacts, which are intended to simulate the humping of freight cars and the general rough handling received in transit.

Vibration tests are conducted on shaking machines that can soon wreck either a poorly packed item or a poorly made item. This test, of course, is similar to the vibration encountered during shipment but is highly intensified to speed up action and point out possible weaknesses in either the container or the product. A package under such test is shown in Figure 3. Compression tests, either flat, diagonal edge-to-edge, or diagonal corner-to-corner are used to check stacking strength or resistance to distortion of various panels of the container. This test is shown in Figure 4. These tests are most frequently used for a fabricated container packed with the product to be carried. Equally important are tests conducted on the component parts on the container, particularly for corrugated types. Included are Mullen or Cady tests, ring crush tests, flat crush tests, puncture tests, tearing tests and many others, which should be conducted under controlled conditions of temperature and humidity as illustrated in Figure 5. Testing can range from rolling a package down a flight of stairs to highly scientific studies with G-meters, accelerometers, oscillographs, and amplifiers as used by railroads and government agencies. In-

Figure 3.—Intensified vibration such as encountered during shipment is simulated here.

telligent use of such tests can point out possible weaknesses in either the product or the container and permit correction before mass shipments start.

The A.S.T.M. has established standard methods of conducting these tests, although performance standards are yet to be suggested. One of the first attempts to standardize on performance requirements was made by the National Safe Transit Committee, under sponsorship of the Porcelain Enamel Institute. The committee, composed of members selected from shippers, carriers, and container manufacturers, after a thorough study, established a pre-shipment test series which required a vibration period of one hour on a shaker set to produce deceleration of not less than one G, followed either by a series of drops, or by a cycle of blows on an incline impact testing device sufficiently severe to produce fifth zone shocks as measured by a ride recorder. The test is very severe and experience has proved that items which pass it safely can be shipped with minimum damage.

Specifications

Compliance with specifications, e.g. with requirements of the railroad and motor freight classifications for the product packed, are important to avoid rate penalties. There are also definite packing specifications for the transportation of dangerous articles under ICC regulations. Neglect of any such specifications by a packing engineer may result in heavy penalties or in rejection of boxes. If a government order is involved, the packing section of the contract covering the item must be thoroughly checked. It will probably require that the package comply with a government container specification.

Costs

Costs are always important, but they are emphasized to the point where safety may be endangered. Being overhead, shippers are usually fighting to save pennies in package cost, which is what makes package engineering the science it is. It would be easy to pack most items so that damage would be negligible, but to do so at minimum cost is another matter. It requires consideration of the type of container best suited for the particular item, as for instance, whether it should be an open crate or closed package. There are usually alternate types of containers to consider for each packaging problem. Size and the shape of the container also affect its cost and its resistance to rough handling. For example, a cubical package generally offers greatest resistance to rough handling, but may not be cheapest. Actually the important cost figure is that of the packed item delivered to the eventual consumer and it includes the following items:

1. Initial package cost.
2. Package storage cost.
3. Empty package handling cost.
4. Package assembly.
5. Packing time required.
6. Closing of container.
7. Handling of the packed container.
8. Transportation charges on tare weight of package.
9. Unpacking costs.
10. Salvage or reuse value.

All these facts must be properly weighed and considered in arriving at the final cost figures, and the package that the salesman offers for $1.99 may cost more in the long run than the one selling for $2.35. A good cost analysis requires a lot of work, but can really pay off.

Handling Requirements

Handling requirements are very important both from the cost picture and because they often actually determine the package design. Conveyor

Figure 5.—Other tests are conducted in this room under controlled temperature and humidity conditions.

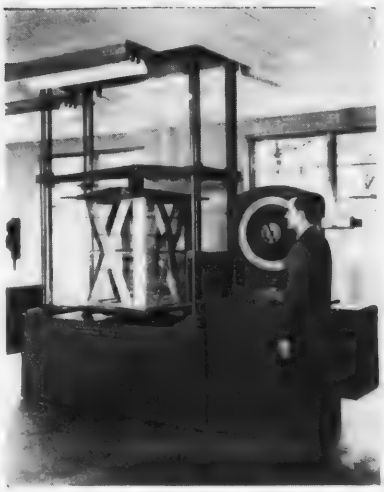


Figure 4.—Various compression tests are made on this machine.

lines present problems that differ from those found with spot or table packing. Space available must be considered. Men and equipment required also are important. Consideration also must be given to the handling to be expected after shipment is started. Will shipment be on company owned trucks or by common carrier? Will shipment be to distributors with subsequent break-down of package and reshipment to consumer, or will it involve export shipment? Each type of shipment implies different handling and a variation of the hazards apt to be encountered and for which protection must be provided. Some of these hazards to think about:

1. Shocks, drops, or blows due to rough handling.
2. Crushing by applied stacking loads.
3. Puncture by sharp objects.
4. Moisture due to the elements, or dampness from high humidity.
5. Vibration in transit.

Design

We have considered many factors affecting design, but have said little about design itself. Design is where experience and common sense come to play, since each item presents its own peculiar problems. The strength required in a package is dependent upon the weight, size, and type of load carried. Easy loads and bulk loads require designs complying with the strength requirements of industry specifications according to weight and size. Type 3 loads require in addition secure anchorage of the item within the crate either by bolting, blocking, strapping, cushioning or suspension. In many package engineering laboratories, containers are designed to carry items ranging from a two pound neon

sign to a 2000 pound machine. The only thing such products have in common is that they all may be treated roughly and carried on any face despite all labels and warnings to the contrary. It's up to the packaging man to design the container accordingly. Product engineers occasionally design items that perform perfectly once in use, but they may neglect to take shipping into consideration. Thus, sometimes the package engineer may suggest a minor and inexpensive change in the product to make it far easier and cheaper to ship.

There are other phases of package engineering and this has only highlighted some of the problems considered. There are many publications on packaging, but the questions that come up in the work can't all be answered from textbooks. On the other hand, like items require similar treatment, and past experience will often provide the answer.

Research in this packaging field is important to the Forest Products Industry and to this Society. Between 15 and 20 percent of the total production of lumber is used for boxing and crating, much of this in the lower grades otherwise difficult to market. Likewise, approximately 25 percent of the total production of paper is used in the packaging industry. Thus, it is an important market for the Forest Products Industry, but it is one that is somewhat vulnerable. Other industries are constantly seeking substitute materials for these wood products. Any research leading to more efficient utilization and to better products either by the container manufacturer or by the raw material supplier helps to stave off substitute materials and preserve this important market. Packaging is now considered to be a $9,000,000,000 a year industry, and proper design can save tremendous sums both in package costs and in damage claim reduction. Fortunately, this fact is being given more consideration each year and the work of industrial packaging engineers along with general research in this field is constantly being given increased recognition and support. This is exemplified by this program itself as a relatively new field for your Society, and it is a pleasure to take part in it.

Discussion

C. J. Menkick (Motorola, Inc., Chicago, Illinois): Is the packaging research you refer to, designed to reduce the cost of packaging, or is it geared primarily to reduce damage?

Mr. Ladd: Both, with neither taking precedence. The objective of packaging research is to develop information that will make it possible to design packages that will get the merchandise packed to the consumer at the lowest possible cost and with a minimum of damage. The point of most favorable balance between packaging cost and damage incurred depends, of course, upon the type of merchandise packed.

A. J. Panshin (Forest Products Department, Michigan State College, East Lansing, Michigan): Is furniture included in the packaging standards of the National Safe Transit Committee?

Mr. Ladd: The National Safe Transit Committee was first sponsored by the Porcelain Enamel Institute. Their activities have been expanded to include other commodities but to the best of my knowledge Television sets are the only furniture type articles that come under their present program.

Earl R. Stivers (Packaging Research Laboratory, Rockaway, New Jersey): You have discussed several types of container testing methods or procedures. Do such things as the type, shape and loaded weight of the container affect the selection of the test procedure to use?

Mr. Ladd: Yes. Very seldom, if ever, are all of the container tests used to evaluate at given container or packaging method. Rather, the test or tests to be used will be selected on the basis of such considerations as expected destination of the container and contents, type of handling and exposure anticipated, nature of the contents and the size, shape and weight of the container and contents.

W. J. Dunn (Winnebago Cabinet Company, Rockford, Illinois): How does the 7 million dollar damage loss resulting from the shipment of furniture compare to that sustained by other commodities? Why is the furniture loss so high?

Mr. Ladd: The 7 million dollar furniture damage is the fourth highest in the country. The three classes of freight that exceed this loss include perishables such as food.

Furniture damage is high compared to that incurred in the shipment of other durable goods because such damage as a scratch that would be relatively insignficant on other goods is a severe defect on a highly polished wood surface. These surfaces could be, and often are, adequately protected but the packaging of furniture is highly competitive and adequate protection is often sacrificed in favor of reduced packaging costs.

J. R. Watkins (Watkins Patents Inc., New Haven, Connecticut): Has there been an improvement in damage to furniture since the adoption of definite container specifications by the railroads?

Mr. Ladd: I believe the packaging requirements included in the Freight Classifications are considered to be quite effective. It is extremely difficult, however, to develop general packaging specifications that will apply to a wide variety of packaging requirements and still give good results in every instance.

Mr. Stivers: Have the loss and damage claims for furniture increased with the wide spread increase in the use of fiberboard by this industry?

Mr. Ladd: That is an interesting question, but I am unable to answer it. Would anyone here care to answer or comment in this regard? (No comments)

Lee Moffett (Tarter, Webster & Johnson, Inc., Stockton, California): What are the principal features of steel drum packaging that make it preferable to nailed wood crates for packaging aircraft engines?

Mr. Ladd: Under present conditions the steel drum is a heavier container but is more easily used to afford Method II protection to the contents. Adequate research in this field might change this situation.

Wood Fiber Felts for Protective Packaging

E. O. LIEBERG

Manager, Industrial Sales Engineering Dept., Wood Conversion Co., Cloquet, Minnesota

The basic requirements of protective cushioning materials are outlined with a description of a felt type material manufactured from refined wood fibers and various binders. Basic data relating to the compression properties, resiliency, abrasion characteristics, staining characteristics, moisture absorption and thermal conductivity are given for the wood fiber felts as a means of showing how these materials are adaptable to protective cushioning.

OUR PRESENT STANDARD of living is based on a great variety of materials and products whose distribution is directly dependent on packaging and handling methods which deliver these materials and products to the end user undamaged. Both packaging and materials handling methods became vitally important during World War II when we were faced with the problem of supplying military forces scattered over the globe with the modern equipment and materials they needed. Increasing emphasis was put on packaging procedures and the study of packaging materials not only by the government but also by many of our large industrial organizations. While wartime packaging might be done with little regard to cost, the eventual application of protective packaging must be based on adequate protection for the least possible cost. The overall problem involves the coordinated application of many types of items such as crates, cartons, wrappings, labels, tape, and protective cushioning which might be used singly or together for protection of a specific item.

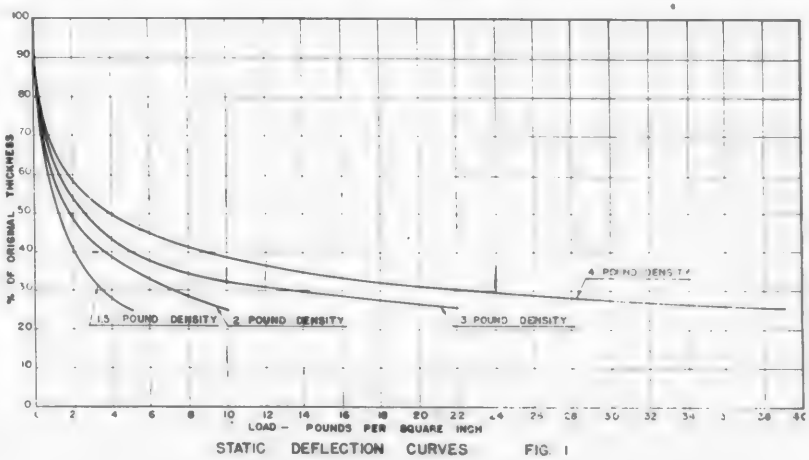
There is a large group of materials which qualifies as protective cushioning materials including nearly all of the pad type products such as the rubber products and rubberized fibers, many types of hair, wool, and cotton felts, and a large number of converted wood products including various forms of paper and excelsior. This paper deals with one specific product of the last group, namely, the wood fiber felts.

In many cases materials which were developed originally for other uses have been found to have properties which could advantageously be used in packaging either in their original form or in some modified form. Such is the case of the wood fiber felts. While their original form was aimed at thermal insulation, their compressive characteristics indicated applications in the protective cushioning field. With certain modifications they have become a very versatile protective cushioning material.

Requirements of a Protective Cushion

Protective cushioning materials as used by the modern packaging engineer may serve several purposes in a single application. For broad usage in package application protective cushioning materials must offer a wide variety of properties as described in the following paragraphs.

1. Shock and Vibration Protection: Basically a protective cushioning material is thought of as a material, capable of absorbing forces due to shock and vibration. During the handling and shipping of any item it is subjected to many conditions which develop shock or vibratory forces such as packages falling, rough roads during truck shipment, and normal transportation vibrations. All of these are cases in which an outside condition has put the shipped item in an accelerated motion which must be stopped in a relatively short space. Protective cushioning materials are a means of controlling the maximum deceleration in bringing these shipped items to rest. The compression of a protective cushioning material under an item which is dropped to a solid base slows the process of coming to rest and absorbs some of the force which has been generated due to the motion of falling. The variety of sizes, shapes, weights, and degrees of fragility found in items requiring this type of protection combine to make an almost infinite number of economical cushioning requirements relating to protective cushion thickness and shock absorbent



STATIC DEFLECTION CURVES FIG. 1

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characteristics. Add to this the various conditions of handling and shipping, which actually vary from movement by rubber-tired carts on smooth floors to drop deliveries from airplanes, and you have some idea of the scope of application necessary in this requirement alone.

2. Surface Protection: A protective cushioning material is often placed next to a highly finished surface and must therefore be of such a nature that it does not stain, mar, ar abrade the surface. In many cases, protection against staining, marring and abrasion is a primary function of a protective cushioning material and it must have a ruggedness which will withstand the action of surrounding materials.

3. Neutral and Non-Corrosive: The shipment of metals adds another requirement for protective cushioning materials. Any material that is exposed to bare metal surfaces, particularly highly finished surfaces, must be relatively neutral and non-corrosive.

4. Controlled Absorption: While general shipping does not have special requirements regarding moisture absorption, under special conditions either high, rapid absorption or low absorption are necessary. Liquids in shipment require a protective cushioning material which will absorb very rapidly any possible leakage and thus offer protection to the rest of the shipment. The opposite is true of solid object shipments which might be subjected to high moisture conditions. Here a protective cushion must resist absorption to maintain its efficiency and to assist in the prevention of corrosion. Another special case requires that the protective cushion retain a quantity of moisture which it gives up gradually during the shipment of certain vegetables such as asparagus and celery to retain their freshness.

5. Thermal Insulation: The handling and shipment of materials such as liquids and perishables which are affected by temperature require protection against outside temperature conditions. It is therefore convenient to use a protective cushion which is a good thermal insulator.

By taking advantage of protective cushioning materials which have many of these requirements the packaging engineer is able to do several jobs with one material, showing a savings in material costs, handling, and shipping weights.

Wood Fiber Felts

Most of the protective cushioning materials are based on some type of fibrous material, either animal or vegetable. One of the most plentiful and economical is, of course, wood fiber in its various forms. This paper is confined to a discussion of a felt type material which uses wood fibers in the refined state of sulphite pulp as a base material. The sulphite fibers when separated to a state of nearly individual fibers are regrouped and formed into a felted mass using a binder for adhesion.

The resultant homogeneous product is off-white in color with a smooth felt-like nature.

The manufacturing process for such a material offers adequate provision for accurate control of a variety of densities and thickness. Standard wood fiber felts are available in four densities 1½, 2, 3, and 4 pounds per cubic foot. In addition, standard single thickness of ⅛", ¼", ½", ¾", 1", 1½", and 2" are available. The standard binder may be modified with additives which control the absorbent characteristics of the end product or make it fire retardant. Since this is a homogeneous material, the change in binder affects all the material—not just the surfaces.

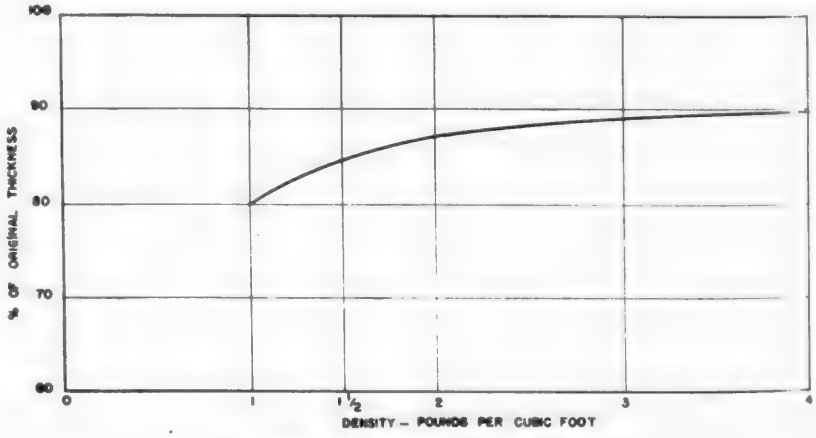
Further variation is possible through various surface treatments. The application of various papers, foils, scrim or cottonet to the surfaces gives added surface toughness and special properties required in some applications. A large variety of surface coatings are available which help develop certain other special surface characteristics.

We will now examine separately each of the requirements of a protective cushioning material with reference to how the wood fiber felts meet these requirements.

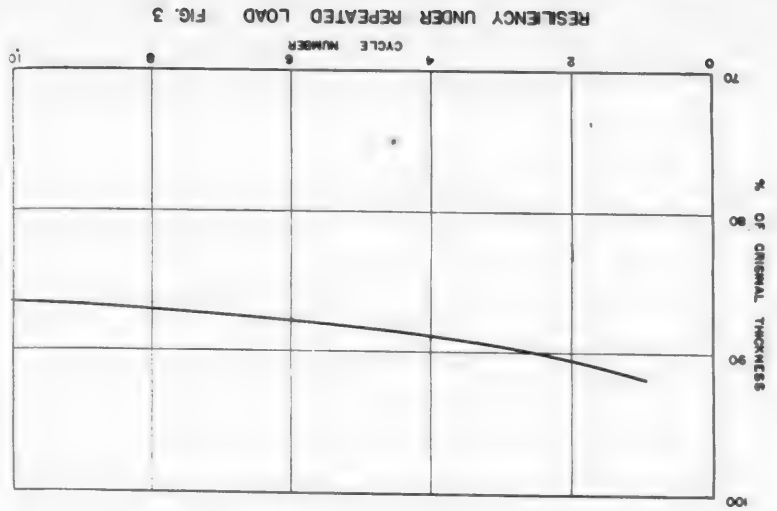
Requirements of Cushioning Material

1. Shock and Vibration Protection: The shock protection afforded by protective cushioning materials is based on the ability of the protective cushion to absorb compressive force. An object dropped from a given height develops a definite amount of velocity. It is the job of the protective cushion to regulate the maximum possible change in velocity (deceleration) when the package is brought to rest. For example, an instrument box is placed in a carton which has a two inch protective cushion for a liner. This assembled unit is dropped from a height of 30" on a concrete floor. This whole unit has attained a speed of 8.5 miles per hour at the point where it met the concrete floor, according to the laws of Galileo and Newton. At this point the carton stops abruptly but the instrument box continues to move by compressing the protective cushioning material which gradually brings the instrument box to rest.

It is possible to calculate the thickness of protective cushioning required from data available in static deflection curves of the protective cushioning material, provided the fragility of the item to be shipped is known and the maximum shipping conditions are known. The fragility of an item is generally specified as maximum acceleration or deceleration which the item can safely stand. Knowing the maximum height of drop, weight of the item, size and shape of the item, and maximum deceleration which it will stand a maximum unit load as applied to the protective cushion can be calculated. With this figure a cushioning material can be selected from the static deflection curves which show compression per unit load and the required thickness can be calculated using protective cushion efficiency and maximum deflection from the curve and the height of drop and fragility already referred to. There are actually several variations in the details of the calculations mentioned; however, since it is a complex subject within itself, we will not attempt to go into the details in this paper.



DENSITY RESILIENCE CURVE FIG. 2



Examination of figure 1, the static deflection curves for the wood fiber felts, shows a rather wide range of unit loads which can be handled by the four standard densities of this material. Assuming maximum compression to 25% of the original wood fiber felt thickness, these materials will handle unit loads up to 39 pounds per square inch. Most efficient use can be made of these materials by using 1½ pound density from 0 to 5 pounds per square inch maximum unit load, two pound density from 5 to 10 pounds per square inch maximum unit load, 3 pound density from 10 to 22 pounds per square inch maximum unit load, and four pound density from 22 to 39 pounds per square inch maximum unit load. Since the wood fiber felts are homogeneous in nature they offer consistent performance in each thickness. Their performance is also unaffected by temperatures normally encountered under handling and shipping conditions.

A second factor has an effect on the efficiency of shock and vibration absorption. A material must have a relatively high resilience to offer protection for a series of shock loads as is found in most handling and shipping conditions. Figure 2 is a curve showing percent recovery of various densities based on a test compressing a sample to one third its original thickness where it is held for one minute and released. The final thickness is measured one minute after release and stated as a percentage of the original thickness. The 83 to 90 percent return as indicated is considered good for the cellulosic group of materials. Figure 3 indicates another interesting resilient property, that of return under conditions of repeated impact. Because most packaging applications eventually involve a series of shocks, it is important to know when most of the "set" in a cushion is established. As figure 3 shows, this curve straightens out with very little loss on compressions above number 10.

2. Surface Protection: In addition to protection against shock and vibratory forces, many products require a protection against abrasion, marring or staining of finely finished surfaces. This is particularly true of finely finished furniture, appliances, machined parts, or soft sheet metal surfaces.

The fibrous content of wood fiber felts derived from the sulfite process has a pliable, resilient quality. When held in a felted blanket by a binder the result is a material which is non-abrasive to the most delicate surface. Tests have shown that many thousands of passes over a standard furniture finish leave no sign of abrasion. In addition the firmness of these felts offers added protection against marring from pressures of other items which may be brought to bear on the surface area.

The application of the wood fiber felts for surface protection generally makes use of some form of liner. The bare felt surface is always applied next to the surface requiring protection, but the use of paper, scrim, or cottonet on the outer surface toughens this surface and adds tensile strength for application purposes. Typical applications are shown in figures 4 and 5. Figure 4 is a standard furniture wrap using a ¼" wood fiber felt with kraft paper backing. Figure 5 is an approved method of shipping aluminum canoes using a ½" wood fiber felt with cottonet surface.

3. Neutral and Non-Corrosive: The white finishes used on appliances form the basis for a test on staining characteristics. Both laboratory tests and actual use have shown no stain on these surfaces. The effect of felts on bare metal surfaces is minimized by maintaining a neutral pH between 6 and 8 on one type. Figure 6 shows pressure point padding on a highly finished metal surface.

4. Controlled Absorption: There are two extremes relative to absorption requirements of packaging materials. The standard wood fiber felt material which is adequate for general packaging purposes may be modified by binder additives to meet the requirements of high rapid absorption or resistance to absorption. Both of these requirements are established in Federal Specification UU-C-843, "Cushioning Materials, Cellulosic".

The non-absorption requirement is used in the shipment of materials subjected to high moisture conditions and where corrosion might be increased through the absorption of moisture. All of the vegetable fiber materials tend to lose resilience under conditions where they absorb moisture. The non-absorbent treatment greatly mini-

Figure 4.—Product is excellent for protecting furniture.

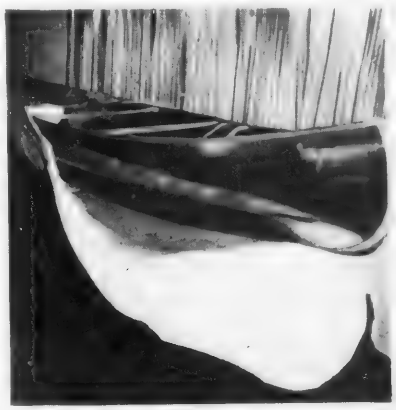


Figure 5.—Typical use protects canoe finish in transit.

Figure 6.—Used as corner protection for shipping appliances.

mizes the absorption of liquid water. The treatment can be carried to a point where the felt will float on the surface of water for several months. One laboratory sample went eight months.

The reverse property, that of high rapid absorption, is required in the shipment of liquids. In addition to protection against shock it is often advantageous to have a material which will absorb any possible leakage and thus prevent damage to other items in the shipment. The highly absorbent wood fiber felt will absorb 16 times its own weight of water in 30 seconds when placed on a water surface. Figure 7 is a picture of such a package designed to absorb the contents of the bottle.

The shipment of stalk type vegetables such as asparagus and celery requires a protective cushion which not only protects against shock but acts as a wick, delivering water to the stalks through the cut ends during shipment. The pads of wood fiber felt are thoroughly soaked prior to shipment and retain a large volume of water which when passed on to the vegetable during shipment assures its delivery in a fresh, crisp condition.

5. Thermal Insulation: Recent increases in the general use of frozen foods, and the shipment of fresh perishables, have increased the need for packaging materials which are good thermal insulators. The wood fiber felts have a K factor of 0.23 B.t.u.'s per hour per square foot, per inch of thickness, per degree temperature differential. This offers important protection against both heat and cold. Cartons lined with these materials are used to help keep frozen foods and ice cream in a frozen state during shipment. On the other hand, car padding used to line the floor racks of refrigerator cars for potato shipments not only protects against bruises but also offers protection against the freezing of winter shipments.

Packaging Specification Approval

Earlier, Federal Specification UU-C-843, "Cushioning Materials, Cellulosic" was mentioned. The wood fiber felts are available in all types of absorbency and classes of density as established in this specification. In addition they of course comply with other specifications referring to UU-C-843 such as MIL-F-5610, "Packaging and Packing of Parachutes for Shipment and Storage" and T-VA-F-440[illegible]a, "Chairs, Side".

The furniture industry has established with the railroads certain specific methods and materials for packaging furniture items. These are specified in the Consolidated Freight Classification. The Consolidated Freight Classification in Item 19501, Note Two, approves the cushioning materials to be used in furniture packages. Paragraph four, under Note Two of Item 19501, describes the wood fiber felts. This particular item is approved for specific furniture packages, which in turn are required for certain freight rates as established by the Classification.

The United States Post Office Department, in its bulletin on the packaging and preparation of mail matter, approves the wood fiber felts for both cushioning and absorbency referring to them by their trade name, Tufflex.

Handling of Wood Fiber Felts

A packaging material to be good must have more than the properties just discussed. It is necessary that it be easy to handle and cut to size, that it be dimensionally stable so that pieces used on a packaging line will each fit its exact location and perform an equal job on each application. The wood fiber felts are unique in filling these requirements.

Discussion

J. R. Watkins (Watkins Patents Inc., New Haven, Connecticut): What methods are used to cut these wood fiber felt material into the desired shapes?

Mr. Lieberg: They are easily cut to any desired shape by a variety of methods. Various paper and cloth cutters and die-cutters are used as well as saw-type tools.

W. J. O'Neil (Dept. of Forestry, University of Missouri, Columbia, Missouri): If subjected to warm, humid conditions, would this material absorb sufficient moisture to be harmful to a finely finished surface such as that of a table top?

Mr. Lieberg: No. Not unless these atmospheric conditions were abnormally severe.

Figure 7.—Absorbent qualities are important in case bottle breaks.

E. R. Stivers (Package Research Laboratory, Rockaway, New Jersey): Does temperature affect the protective characteristics of these materials?

Mr. Lieberg: Very little. They perform satisfactorily at temperatures ranging from sub-zero to the charring temperature of the felt. Incidentally, a fire retardant blanket is available for special use applications.

Robert A. Ferrell (Kennedy Car Liner and Bag Co., Shelbyville, Indiana): Are not wood fiber felt cushioning materials subject to deterioration due to fungus attacks?

Mr. Lieberg: The material is treated with a fungicide which protects it from fungus activity.

J. R. Roberts (Development Department, Weyerhaeuser Timber Company, Longview, Washington): How are the natural absorptive properties of wood fiber felts controlled? For instance, how is a non-absorptive blanket made?

Mr. Lieberg: The absorptive properties of a felt may be modified by the use of binder additives. For example, wax emulsions may be added to produce the resistance to absorption you refer to.

Mr. Watkins: What species does your company use to produce wood fiber felts?

Mr. Lieberg: We purchase processed pulp which is largely spruce and hemlock.

M. B. Christian (Chicago Mill & Lumber Company, Tallulah, Louisiana): Would you mind telling us what fungicides are used to control fungus growth in wood fiber felts

Mr. Lieberg: I am not sure that I can answer your question completely but I can give you two examples. Dowicide or Permatox are used for this purpose.

Craveneer as Used in the Packaging Field

ARTHUR L. WHITON

Sales Manager, Chicago Mill and Lumber Company, Chicago, Ill.

Describes briefly the reasons why Chicago Mill and Lumber Company searched for and developed a new container material known as "Craveneer". The product is composed of a sheet of single ply veneer and two sheets of 42 pound kraft paper. One ply of paper is laminated to each side of the veneer as it comes directly from the lathe and the combined sheet is then put through a Coe dryer. This drying operation, after fabrication, eliminates practically all normal shrinkage.

EXCESSIVE DEMANDS on raw material resources during World War II led to the development of many new and improved materials in the packaging field. Weatherproof V and W board cartons were among these developments. These light-weight containers were a definite contribution to the war effort and to the conservation program.

During the last year of the war nearly fifty percent of the lumber produced in this country was used in the manufacture of shipping containers and, naturally, all aggressive container manufacturers were constantly searching for new and better materials that would reduce this terrific drain on their timber resources. A product with the copyrighted name of "Craveneer" was one of the results of this research program.

Through many years of operation in the wooden box industry, Chicago Mill and Lumber Company had accumulated large acreage of low grade timber not suitable for its general line of production and a product was needed that could utilize this low grade timber, as well as assist in the overall conservation program.

Development of Craveneer

After many months of research, our chemists and engineers found that they could successfully laminate kraft paper to wet veneer and not only obtain a strong, one piece panel but a panel that would withstand unlimited soaking and drying tests without delamination.

The next problem was to determine what kind and weight of paper would give the best results when combined with various thicknesses of veneer. Laboratory tests indicated that Fourdrinier kraft weighing 42 pounds per 1,000 square feet seemed to effect the best balance when laminated to veneer thicknesses of $\frac{1}{16}$", $\frac{1}{8}$", and 1/6". The next step was to test boxes made of the three thicknesses and determine their relative strength as compared to the plywood, single ply veneer and resawed materials used by the company, in large quantities, in the manufacture of cleated boxes and wirebound boxes and crates. The following table indicates some of the savings that could be made through the substitution of this new material.

COMPARABLE THICKNESSES OF CRAVENEER, PLYWOOD, SINGLE PLY VENEER AND RESAWED

Craveneer	Plywood	Single Ply Veneer	Resawed
*1/16"	3/24"	1/10", 1/8", 1/7"	---
*1/8"	3/20", 3/16"	1/6", 3/16"	---
*1/6"	3/12"	7/32", 1/4"	1/4"

*Thickness of wood core exclusive of the paper face.

In addition to the material savings shown in the above table, it was also found that logs that could not be used successfully in the manufacture of plywood, single ply veneer or thin resawed material would make excellent Craveneer. Knots that would normally fall out of single ply veneer during the drying process would remain intact in the wet veneer until thoroughly glued in place in the laminating process. Also kraft paper being securely bound to each face of the veneer, before the panel was dried, reduced normal shrinkage about seven percent. When you combine all of these savings, with the greater production obtained on the comparatively fast laminating machine, you can understand why our company was sure that this material had a very bright future.

When the laminating machine had been perfected and was ready to go into operation, Craveneer was introduced to some of the Military Services and prompt approval was received after the agencies had witnessed tests made on boxes manufactured of this material.

Kraft paper was on the critical list at that time but the many desirable qualities of Craveneer, plus the raw material savings that could be effected, enabled the company to secure the necessary paper tonnage. Many thousands of cleated Craveneer boxes were manufactured and shipped overseas before the war ended.

Merchandising of Craveneer

We now come to the merchandising of Craveneer in the peacetime market and its position in the "defense program" packaging field.

The production of plywood boxes in this country is somewhat limited, and the industry is never in a position to meet demands when the appliance, piano, casket, and other similar industries are running at full capacity. This condition existed for nearly four years after the war ended and it was during this period that a large percentage of our Craveneer production went into the manufacture of cleated boxes for these industries. It helped us meet the requirements of our customers and retarded the development of inferior packages for these products. Craveneer supplied the tight, rigid, and lightweight boxes required by the manufacturers of these valuable and highly finished products. The smooth, uniformly colored, one piece panels made ideal printing surfaces for the desired advertising, and this feature aided materially in the sale of

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Craveneer boxes.

Single ply veneer and thin resawed material, used in the manufacture of wirebound crates and boxes, was also very scarce during this postwar period and, again, Craveneer came to our rescue. The thinner Craveneer slats and panels were used in place of the single ply veneer and resawed material and many advantages resulted. The various panels of a wirebound box, when made of single ply veneer or butt-jointed resawed material, generally consist of several pieces in each face of the box and when exposed to varying atmospheric conditions shrink and warp and openings develop between the multiple pieces. This is not a serious defect for the majority of products packed in wirebound boxes but does prevent the use of this type of box for small, unpackaged items such as bolts, nuts, screws, etc. The Craveneer wirebound box is made with one piece panels and can be used for packing these small, bulk packed items as well as afford much greater protection from the elements for any highly finished article or any items prepackaged in corrugated cartons and overpacked in wirebound. Much greater rigidity is also obtained through the use of one piece panels. All of these features when combined with the rather substantial savings in freight, to not only the box user, but also to the ultimate consumer, plus the excellent appearance of the box, whether plain or printed, combine to give the customer the type of wirebound box he has always wanted but has never found before.

Craveneer is also used extensively in the manufacture of wirebound crates. Its inherent rigidity makes possible the use of slightly wider but straight slats of this material as a substitute for veneer or resawed diagonals. The wider slats give added protection to the article packed in the crate and also afford a better printing surface for the company name and the desired advertising matter.

As a box and crate manufacturer, Chicago Mill and Lumber Company is now supplying Craveneer packages for shipment, both domestic and export, of a long list of products such as refrigerators, freezers, pianos, furnaces, stoves, water heaters, textiles, caskets, sewing machine cabinets, washing machines, automatic clothes dryers, porcelain enameled sinks, undersink cabinets, wall cabinets, food, clothing, medical supplies, hardware, aluminum and stainless steel sheets, and many other miscellaneous items.

In the export field Craveneer solved a serious pilferage problem for a customer manufacturing plumbing hardware such as brass fittings and faucets. The loss by pilferage had become a very disturbing factor to the shipper and the insurance companies. The ¾" oak box, lined with ⅜" resawn oak placed at right angles to outer sheathing did not stop the substantial losses. At the customer's suggestion, we submitted a wirebound box constructed with butt-jointed ¼" thick resawed lumber on the outside face and ⅛" thick Craveneer panels on the inside face. The two panels were securely joined together with well clinched staples in the normal wirebound manufacturing process and this feature, combined with the regular twisted wire closure, completely eliminated the pilferage problem. This lightweight container showed a saving in domestic transportation costs to shipside, a reduction in ocean freight because of the lesser cubical displacement, and a very handsome saving in the original cost of the package.

This particular package won first prize, over all other types of containers entered in competition in the export field, at the Annual Exhibit of the Society of Industrial Packaging and Materials Handling Engineers held in Cleveland in October 1951.

The highly weather resistant characteristics of Craveneer has won favor with certain of the Armed Forces packaging personnel. The majority of plywood produced for packaging purposes will not withstand long periods of out-of-doors storage and the high grade weatherproof plywoods are too expensive for use in boxes, except for reusable purposes.

Craveneer will not delaminate. The paper coating may bleach and possibly be scuffed off in spots from contact with other containers, when the surface has been soaked for a long period of time, but the box is not materially weakened. If plywood panels delaminate, the box is ruined.

In the manufacturing process, Craveneer is given a surface treatment of wax which adds sufficient protection to the paper to withstand many months of out-of-door storage without harmful bleaching or softening. However, if greater weatherproofness is required we can add, at a comparatively low cost, a heavy dry wax finish to the exterior surfaces. This highly weather resistant feature, when considered in conjunction with the added strength and protection of the one piece panels supplied in all boxes, whether wirebound or cleated, deserves the serious consideration of all Government agencies.

We have supplied many thousands of Craveneer containers to contractors who are shipping expensive and highly finished articles to the Armed Forces, and have as yet to receive our first complaint. This has not been true with our veneer wirebound and plywood containers.

Although we understand Government specification, it is a fact that nature, and not man, grows the trees—and inspect as carefully as you may, certain objectionable knots and cross-grain will creep into the boxes and the inspector will throw them out. These rejections are a total loss to the manufacturer and a waste of our natural resources. When you combine this same objectionable veneer with paper and glue, the defects are gone and a new strength is acquired.

We have not searched for other uses for this material outside of the packaging field but have sold substantial quantities to the furniture industry for use as drawer bottoms, case backs, and couch bottoms. We have also sold Craveneer to the pipe line companies for use, as a wrapper to protect the corrosion preventive finish on the surface of the pipe, when laying the pipe in rocky soil. This business has come to us unsolicited.

Craveneer has recently been introduced in the fruit and vegetable field and preliminary surveys indicate that its fine appearance, smooth surface, lightweight, and water resistant characteristics, all combined into one product, will supply a much desired and badly needed material in this field. It is estimated that there is a potential annual volume of approximately 600,000,000 feet in the citrus field alone, and this figure could be increased substantially if adopted by some of the vegetable shippers.

Summary

It is a known fact that good veneer logs are becoming scarcer and more expensive each year. The large hardwood timber tracts have been cut over two or three times and the trees that remain are of inferior quality, or are of species that will not make a good grade of plywood or thin single ply veneer. However, these trees will make satisfactory Craveneer and can be purchased at a reasonable price. In fact, in certain areas in the South the large paper companies are anxious to have the oak, ash, and other hardwood species removed from the land so that they can plant pine for their pulp mills. Craveneer is the answer to this problem, as well as to the all important one of extending the life of our timber holdings.

During the past eight years Chicago Mill and Lumber Company has produced approximately 675,000,000 surface feet of Craveneer, which clearly indicates that the product has considerable merit and a definite sales appeal.

Ply-Veneer Shipping Containers

J. R. ROBERTS and A. M. FISKEN

Manager and Project Engineer, respectively, Development Center, Weyerhaeuser Timber Co., Longview, Wash.

Ply-Veneer is made by continuously assembling two layers of Kraft board on the outside of a distended veneer core. Containers made from this product are said to combine all the best features of corrugated, solid fiber, wire bound and wood boxes without including the shortcomings of these products. Used for both cleated and uncleated boxes, wrap around shells, and as flat stock for container parts. Is flexible enough for cylindrical shipment protectors.

WEYERHAEUSER TIMBER COMPANY is currently introducing to the market an improved structural material called Ply-Veneer. The product is a highly stable, flexible material comprising specially treated wood veneer to which is adhesively attached one or two flexible liners, preferably of thin Kraft container board. The manufacture and sale of such a product is of marked value to the Company in economically upgrading its forest raw materials through improved integration procedures.

The combining of wood veneer with liners of various kinds to produce a laminated structure useful in the field of packaging is not new. The prior patent art is rather voluminous and discloses a variety of constructions and uses.

However, the prior art products have apparently not enjoyed the volume use to which their basic characteristics entitle them. This may have been partially due to not meeting the detailed requirements as completely as is desirable or perhaps to lack of the ideal manufacturing situation with respect to availability of the components at their source.

In any event Ply-Veneer has been perfected to provide a versatile composite structure capable of a high degree of compliance with the requirements of a variety of uses, manufactured where the integration of veneer, container board and wooden parts if required is ideal.

Ply-Veneer has been in the development and market testing stages for several years. The Elmendorf Research Laboratory has worked with Weyerhaeuser Development on this product —particularly in the fields of container design and product testing. This year for the first time, Ply-Veneer is being produced and marketed in substantial commercial quantities.

Ply-Veneer is used principally as the base material for complete shipping containers and to a lesser degree as container parts. It also has many applications in flat sheet stock in the furniture and allied industries. In somewhat different forms it has applications in the Building Industry which have not yet been completely explored.

Distention of Veneer

When standard veneer is incorporated in a lined composite structure, there is a definite tendency to warp. This warping problem is overcome in Ply-Veneer by giving the dry veneer stock a distending or stretching treatment prior to applying the Kraft board. In this operation, the veneer is actually lengthened across the grain from five to eight percent over its previous dimension. The distention slices are all made parallel to the grain of the wood. This action removes the "roll" from the lathe cut veneer and truly flattens it. Attempts to get this same result by a haphazard breaking of the wood structure gives results not sufficiently uniform to do the whole job efficiently and reliably.

Steel Strap Reinforces Edges

This special feature of Ply-Veneer gives the container that plus value it needs to hold its dimensions to close tolerances under heavy loading and rough usage. The steel strap, a half inch wide, is countersunk its own thickness into the veneer on what will be the outside surface of the box, before the Kraft layer is applied. This prevents the strap from catching and tearing when loaded containers are skidded over each other. The strap also gives the containers these other advantages:

a. It increases nail holding strength several times. When the boxes are assembled, the nails are driven through the steel strap into the ends.

b. It acts as a hinge in addition to the Kraft when the box is opened and closed.

c. It prevents splitting when heavily loaded containers are dropped.

d. It prevents racking when the loaded box is dropped on a corner or an edge.

e. It makes a stronger box for rehandling where the container is opened back out to its original flat condition before being returned for reloading.

Routing of Veneer Between Liners

Another valuable construction feature of Ply-Veneer is achieved by the way the corners are formed. The veneer is routed for the corners in such a way that the Kraft board both inside and outside the box is continuous. This gives these advantages:

ABOUT THE AUTHOR: ROBERTS, J. R. In charge of all operations at the Weyerhaeuser Development centers, including pilot plants. Attended York College, York, Nebr., received BS degree in electrical engineering from the University of Nebraska. Formerly associated with: General Electric Co., Schenectady, N. Y.; Conditioned Air Equipment Co., Minneapolis; U. S. Ordnance Dept., Minneapolis; Wood Conversion Co., Cleveland, Detroit. Member: AIEE, Engineers' Club, Minneapolis, Detroit; American Society of Heating and Ventilating Engineers; Theta Xi; Portland Industrial Chemists; and FPRS.

FISKEN, ALEX M. Received Bachelor of Engineering degree in chemical engineering from Yale University, New Haven, Conn. Formerly with the Shell Development Co., San Francisco, California. Member of the Longview Yacht Club and the Tacoma Country Club. Joined FPRS, September 1950.

a. A completely flexible corner—and very strong because there is an intact layer of Kraft on each side.

b. A container which can be shipped knocked down and flat the first time and for reshipment without having rough surfaces to catch and tear.

c. A container which is smooth inside and out with no gaping cracks inside to collect dirt when empty or to fill with shipping contents when the box is in use.

Flexibility of Container Design

Ply-Veneer containers represent a box designers delight because of their versatility.

a. Cleated boxes can be built in any number of types. The cleats themselves may be of any dimensions and joint design. They can be fastened to the box shell or to the box end. The assembly is shipped flat to the user where it is very simply assembled. Containers are easily knocked down for shipment back to the starting point for re-use.

b. Cleatless boxes offer any number of intriguing possibilities. With Ply-Veneer construction, it is possible to make a series of very strong containers without the use of cleats. The flat box blank is so routed and slotted that it can be bent into shape and fastened with staples. The inclusion of steel strap as edge reinforcement is particularly worthwhile in structures of this type.

c. Wrap around shells have many uses. They can be used with solid wood ends or ends of other types. They can be produced at a distant plant and shipped flat to the factory of the user. There they can be assembled into completed containers by combining them with box ends from a local source.

d. Box slats, tops or bottoms can be transported in bundles for assembly in the plant of the shipper. They lend themselves to the manufacture and easy assembly of unique types of containers which must meet special use requirements.

e. The following table lists some of the standard Ply-Veneer constructions:

Inside liner	Veneer	Outside liner
.016	1/10	.016
.016	1/8	.016
.016	1/8	.030
.016	3/16	.016
.016	3/16	.030
.030	3/16	.030

Special constructions will be "tailored to the use" of large users.

Weights of Ply-Veneer per square foot, 16 pt Kraft both sides are: 1/10"—0.32#/sq. ft.; 1/8"—0.37#/sq. ft.; 3/16"—0.48#/sq. ft.

Thicknesses shown are for veneer only and are increased by the two container board liners.

f. Comparison of compression and stiffness, strength of Ply-Veneer and Corrugated Fiber Containers.

g. Ply-Veneer Container Performance compared with Wood Boxes. See Tables below.

Analysis of Product

Use Requirements Method of Perfecting the Product and Establishing its Performance has been employed as a method of analysis throughout the development of Ply-Veneer itself and specific containers made from it.

A. Preliminary Investigation:

a. Analysis of Use Requirements for Ply-Veneer.

b. Probability of meeting these requirements.

c. Probable volume of sales.

d. Probable price level—competitive situation.

e. Decision on further developments.

B. Final Investigation, if preliminary investigation is favorable:

a. Correlation of use requirements with Ply-Veneer properties.

b. Test methods to be used in selection of tentative specifications to meet these requirements.

c. Choice of Ply-Veneer product most nearly complying with specifications.

d. Field and shipping trials of this chosen product.

e. Delineation of superiorities and deficiencies of Ply-Veneer in the field.

f. Correction of the deficiencies through cooperation between the customer and Weyerhaeuser Timber Company.

g. Initial order if customer gets attractive utility at a satisfactory price.

Ply-Veneer Advantages

Based on the above type of analysis Ply-Veneer has been developed to have the following advantages:

Appearance: The smooth Kraft board, the built in cleats, and the square full corners give Ply-Veneer containers a very attractive appearance.

Durability: The "routed in" and covered steel strap and the ruggedness of the 3 layer construction combine to give the containers the necessary resistance to puncture and racking under heavy loading and abusive handling and also gives them stacking strength to an unusual degree.

PLY-VENEER AND WOOD BOXES COMPARED

Type Container	Dimension (inches)	Container Weight (pounds)	Diagonal Compression: Max. Load Sustained (pounds)	Diagonal Compression: Compression at Max. Load (inches)	Revolving Drum Test (14 ft.) No. Drops*	Corner Drop Test No. of Drops*
Cleated Ply-Veneer 1/8" Veneer	24x12x12	7.0	1,500	0.56	139	24
Cleated Ply-Veneer 3/16" Veneer	24x12x12	9.0	2,200	0.65	150	26
Cleated Wood Style 4 Box	24x12x12	14.0	580	0.56	47	14

*Load 95–97 #.
A single girth strop used on the Ply Veneer Box—no girth strap on the wood box.
Data obtained from Independent Testing Organization.

FLAT TOP AND SEPARATE LID PLY-VENEER BOXES COMPARED

(Size 64, 72, 80, 88, 100 and 113 Delicious) *

Container	Severe Bruises Per 100 Apples	Percent Apples Remaining Sound
Flat-top Ply-Veneer 11"	24.9	17.1
Separate lid Ply-Veneer	32.7	10.3
Standard wooden box (check)	32.7	13.6

Both types of Ply-Veneer box were packed with no pads or liners. The standard wooden box used as a check was packed using plain sulphite liners as is the case with all standard wooden check boxes used in these tests.

BRUISE PREVENTION OF 11½" PLY-VENEER BOX HANDLED UPRIGHT, COMPARED WITH THE STANDARD BOX

(Size 100 Delicious) *

Container	Handling Position	Severe Bruising Per 100 Apples	Percent Apples Remaining Sound
Flat-top Ply-Veneer 11½"	Upright	15.3	18.0
Standard wooden box	On Side	30.5	7.5

*Tests made by independent fruit commission.

Permanence: The excellent dimensional stability made possible by special construction and the covered steel strap results in a box which can be reused many times. The corner routing of the veneer between both Kraft layers leaves a surface which lends itself to many re-uses.

Handleability: The cleated ends provide convenient ledges for lifting loaded boxes. The knock-down construction makes it possible to reship many containers in a small space. The fact that there are no rough inside slits or cracks in the boxes makes them easier to handle without damage in the knocked down condition. Their light weight adds to their desirability both on loaded shipments and on empty return shipments. The boxes have excellent strength and stiffness "per pound".

Workability: The smooth surfaces make the containers easier to print, label, or otherwise identify with the owners advertising. The ease of assembly and closure are important in this respect.

Uniformity: All containers are made to close tolerances so that one box is just the same size as another. This makes them applicable when automatic loading equipment is used. It also assures the user of quality uniformity.

The combination of the above properties provides a container superior to present types in utility. It incorporates the best features of nailed wood, wirebound and solid fiber into a single product without carrying over the deficiencies of any of them.

Overall Integration with Lumber and Pulp Operation

Plywood: It is a well known fact that the supply of backgrade veneer is much more abundant than that of high grade face veneer. Because Ply-Veneer does not require a high grade veneer, its manufacture helps to establish a balance in the plywood plant. Many logs having a small high quality veneer content would not otherwise be peeled. Now they will be peeled with the outer shell of excellent clear A grade veneer going into plywood face stock and the bulk of the log being used in Ply-Veneer. This increases the realization from the otherwise lower grade log.

The manufacture of Ply-Veneer in conjunction with plywood makes it possible to use an existing green end system including the face and core lathes, barking equipment, etc. It also makes possible maximum utilization of drying equipment.

Container Board is an integral part of Ply-Veneer. The inside part of a low grade log which would not be economically used for either plywood veneer or Ply-Veneer can be converted to Kraft board in the Pulp mill and used in linings of Ply-Veneer.

Cleat stock, which is used in many Ply-Veneer containers can be made from narrow strips for which profitable uses are difficult to devise. With the type of integration described above, the only items required from outside the Company are nails, adhesive and steel strap.

Better Utilization

The large scale production of Ply-Veneer will make possible the marketing of another useful item of commerce while improving Company integration toward maximum utilization of Forest Raw Materials.

Discussion

M. B. Christian (Chicago Mill and Lumber Company, Tallulah, Louisiana): What adhesive is used in laminating Ply-veneer?

Mr. Roberts: The adhesive is selected to match the weather-resistant characteristics of the ply-veneer panel to the expected exposure conditions. For this reason any one of several different adhesives may be used to bond the Kraft board to the veneer core.

Mr. J. R. Watkins (Watkins Patents, Inc., New Haven, Conecticut): Is the method your company uses to prepare ply-veneer from a distended veneer core and two layers of kraft board similar to the Elmendorf method?

Mr. Roberts: The staff of Elmendorf Research, Inc., of Chicago, worked with us in developing ply-veneer. Much of the fundamental research was conducted by their organization.

Ralph Casselman (Paine Lumber Company, Oshkosh, Wisconsin: Is the veneer core green when bonded to the Kraft boards? Are pieces of the core edge glued to form a continuous sheet?

Mr. Roberts: The veneer is dried, distended and then bonded to the Kraft board faces. Edge gluing is not necessary.

O. T. Sands (Sears Roebuck & Company, Chicago, Illinois): How does the cost of cleatless ply-veneer container compare to that of corrugated or solid fiberboard container of comparable strength?

Mr. Roberts: The comparable cost depends largely upon the degree and type of protection the container must give the contents. If a plain fiberboard container would handle the load adequately it would probably be the cheapest container for the job. When the load is such that liners or sleeves must be added to the fiberboard container to afford the protection needed, the picture may be reversed in favor of ply-veneer.

G. G. Garlick (Protection Products Manufacturing Company, Kalamazoo, Michigan): How is the cleatless ply-veneer box sealed? Is this accomplished by the use of glue, as with fiberboard boxes or are other means used?

Mr. Roberts: The cleatless box is fastened with staples.

A. R. Tegge (Quartermasters Container Laboratories, Chicago, Illinois): Is steel strapping always used in the uncleated box blank?

Mr. Roberts: Not always. Whether or not such box blanks contain the reinforcement of the strapping depends upon the use requirements of the container. Sheet ply-veneer is also sold for other purposes in which the steel strapping is not necessary.

TECHNICAL SESSION V—Tue., June 16, 1953, 2:00 A.M.

Subject: Wood Finishing

Chairman: B. E. Clatworthy

Recorder: Howard Rosenberry

The Absorption of Water, Swelling and Solubility of Free Films of Paint

F. L. BROWNE

Chemist, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture[1]

Tests substantiating that free films of house paints soaked in distilled water absorb surprisingly large amounts of water are described. Amount is often more than 1½ times the weight of linseed oil that the film contains. When such films are young, swelling of many paints may cause expansion of surface area as much as 50 percent.

IT IS POPULARLY SUPPOSED that coatings of oil paints and of drying oils are inert or nearly inert to water. Because oil and water are practically insoluble in each other, it is easy to assume that the incompatibility continues after the oil has become oxidized, polymerized, and cross-linked into a gel structure. Nevertheless, more than 30 years ago English (*23*)[2] and German (*14, 29*) workers showed that films of linseed oil after drying absorb a third or even half of their weight when immersed in water for a few days, and Dunlap (*12, 13*) and later Browne (*4*) at the Forest Products Laboratory reported that coating wood with paint, varnish, or oil merely retards without preventing changes in moisture content of the wood. Since then there have been many publications on the absorption of water (*1, 2, 3, 8, 25, 26, 27, 39, 40*) and water vapor (*16, 17, 31*) by coatings of oils and paints and on the leaching of water-soluble ingredients from coatings (*11, 14, 20, 21*). Many of the studies were concerned with the evaluation of rust-protective paints and the mechanism of protection against corrosion for metal (*18, 19, 20, 24, 28, 32* to *38*, incl.). Most observations were made with coatings supported on glass or metal; few on free, unsupported films (*30, 31*). In all of the publications cited, swelling was measured in terms of the absorption of water by the films; no direct measurements of changes in dimensions are reported.

The loss of substance by leaching and the swelling and shrinking from gain and loss of water are surely significant properties of paint coatings about which more should be known before the behavior of paints on exterior woodwork and the chemistry of coating deterioration can be explored to full advantage. Such developments as checking, cracking, curling, flaking, and blistering clearly reveal the operation of sizeable stresses on the coatings. It is commonly assumed that the stresses originate outside the coatings, particularly in movement or development of fluid pressure within the wood surface that supports the paint. The discoveries that water swells many of the paints in common use to a much greater extent than it does wood and that painted surfaces on houses are continuously wet for long periods of time (*15*) strongly suggest that the destructive stresses may arise chiefly within the coatings themselves.

In order to limit the present studies to the behavior of the coating materials themselves without complications from the effects of the substrate, the tests were made on free unsupported films of clear drying oils and oil paints. All of the films swelled measurably when immersed in water, many of them very greatly. The swelling observed was the increase in area, calculated from precise measurements of increase in length and width of the films. (Convenient means were not found for measuring increase in thickness with sufficient precision to calculate volumetric swelling reliably, though it is hoped that some determinations of change in volume can be made in future work.) Films attached to a substrate, of course, cannot swell freely in length and width; length and width must remain fixed by the requirements of the substrate if separation is to be avoided, and any necessary adjustment of volume must be made by change in film thickness. In a substantially rigid medium such adjustment of volume by change in one dimension only necessarily develops internal stresses. By reason of such stresses it may be that films attached to substrates do not absorb so much water as the free films used in these studies, although the data reported in the literature indicate that any such difference is small.

Methods of Obtaining Free Films

Suitable substrates were coated with oil or paint by brushing or by drawing

How the length and width of a marked portion of a free film of paint held flat between glass plates were measured before and after swelling in water by use of a traveling microscope.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italic figures in parentheses refer to Literature Cited at end of the paper.

ABOUT THE AUTHOR: BROWNE, DR. FREDERICK L. B. Chem. degree in 1917 at Cornell University and the Ph. D. degree in colloid chemistry in 1921 at the University of Wisconsin. He first joined the staff of the Forest Products Laboratory in 1918–19 to develop casein glues for the wood airplanes of World War I. In 1921–22 he was a National Research Fellow at Wisconsin. He is one of the "iron men" of the Chemical Abstracts staff and has edited Section 2, General and Physical Chemistry, since 1929. Besides the American Chemical Society, he is a fellow of the American Association for the advancement of Science and the Wisconsin Academy of Sciences, Arts, and Letters, and is a member of Sigma Xi, of the American Society for Testing Materials, and FPRS.

down with a Bird doctor blade. The coatings were allowed to stand 10 days to dry and harden. Some were then stripped from the substrate for immediate testing, whereas others were exposed in an accelerated weathering machine or to natural weathering out of doors for desired periods of time, after which the coatings were stripped from the substrate for testing. These kinds of substrate permitted the films to be stripped off at the desired time.

Flat tinplate (in pieces 3⅝ by 5½ inches) coated on one face held coatings well during natural or artificial weathering, after which free films could be stripped off readily by amalgamating the tin with mercury. Enough coating was scraped off near the edges of a specimen to expose tin, and the specimen was floated on mercury with the coated face down for about half an hour. With care, it was then possible to loosen the coating at one of its edges and slowly peel it from the metal without breaking the freed film, provided that the coating had not been weathered too long to permit moderate bending without breaking. Much trouble was experienced, however, in stripping unweathered coatings only 10 days old without seriously tearing the films. There might be less difficulty if the specimens with young coatings were chilled to 40° F. for stripping. In these studies the amalgamation process was used chiefly for specimens subjected to natural weathering.

2. Flat pieces of glass, metal, or paper coated with a thin layer of silicone parting agent DC–7 (Dow–Corning Co.) applied with a finger can be painted readily, will hold coatings for a limited period of natural or artificial weathering, and yet allow the films to be stripped off when needed for testing. Some of the films for these studies were prepared on siliconed paper. Shortcomings of the method were a graininess in the layer of silicone that was transmitted to the free films and a tendency for some paints to crack and to begin to peel from embrittlement at an earlier stage of natural or artificial weathering than they did on tinplate or on gummed paper. It is possible that both shortcomings might be overcome by coating the paper mechanically with a thinner and more nearly uniform layer of silicone than was possible with manual application.

Commercial gummed (dextrine mucilage) paper, previously saturated with linseed oil, proved the most convenient substrate for most of the present tests. Prior saturation of the paper with linseed oil was necessary because the layer of dextrine mucilage is readily permeable to the oil in paints; if the paper is allowed to draw oil through the dextrine the composition of the paint coating is altered undesirably. Gummed-paper specimens held most paints satisfactorily for 1,200 kilowatt-hours (about 360 hours of ultraviolet light with water spray for 1½ minutes in each 18 minutes), by which time all paints were chalking, most of them very freely, and were greatly embrittled, some to the point of cracking. To strip off the free films for testing, the specimens were placed in a room at 80° F. and 97 percent relative humidity for about 30 minutes to soften the oiled paper, plasticize embrittled coatings, and melt the dextrine mucilage. The films were then peeled from the oiled paper and placed face down on a glass plate while any mucilage clinging to the backs was quickly sponged off with moist absorbent cotton. Alternatively, the specimens were placed on a pad of damp blotting paper, paper-side down, and held flat under the weight of glass plates for half an hour before stripping off the films. A few very soft coatings, particularly those of raw linseed oil containing paint drier, required a special technique in which the specimens were immersed in water chilled to 40° F. for 15 to 30 minutes. The films were then stripped off by loosening the film at a corner of the specimen sufficiently to insert a finger tip, by placing the specimen coated side down in the cold water, and by holding the film firmly against the bottom of the glass water tray while the paper was carefully peeled off. Soft films are very much firmer at 40° F. than they are at 70° or 80° F. But too long a soaking period may blister coatings of paints that swell greatly, and the blisters may remain in the films after they have been stripped from the substrate.

Other Experimental Procedures

Tests were made with 32 coating materials. Four were clear (unpigmented) materials, namely, raw linseed oil, bodied linseed oil of viscosity Z3, bodied linseed oil of viscosity Z6, and a commercial alkyd-resin paint vehicle said to contain 77 percent drying oil and 16 percent phthalic anhydride by weight. These liquids were used also for the vehicles of 23 paints of varying pigmentation ground at the Forest Products Laboratory. Of the 23 laboratory paints, 18 were practicable house paints and 5 were single-pigment paints of scientific interest only. All of the linseed oils and oil paints contained lead-manganese naphthenate driers; the alkyd resin and alkyd-resin paints contained lead-cobalt naphthenate driers. The remaining 5 coating materials were trade-brand paints purchased in Madison in July 1952, of which 4 were products of large manufacturers with national distribution and 1 was a so-called "breather type" or "blister-resistant" paint made by a smaller manufacturer. All of the commercial paints had the formula printed on the label. In this report the composition of paints is expressed by volume in the short notation first described by Browne (*5*) and recently described in this Journal (*6*) and elsewhere (*7*).

Method of applying coatings of controlled thickness by use of a Bird doctor blade and suction plate.

For most of the experiments reported, paints were applied with a Bird film applicator or doctor blade drawn manually over a substrate held firmly on a Bird suction plate. With each paint, specimens were prepared in pairs, one with a draw-down with a blade that left a coating nominally 3 mils thick and the other with a 6-mil blade. Actual thicknesses, however, varied appreciably from the nominal. When made on gummed paper 8 by 10½ inches in size, such coatings were 3½ inches wide and 10½ inches long and were then trimmed to specimens 3½ inches by 8 inches by cutting off the uncoated parts of paper and the first and last parts of the draw-down, which might be of unrepresentative thickness. When made on tinplate the coatings covered nearly all of the surface of 3⅝ by 5⅛ inch specimens, which were not trimmed after coating.

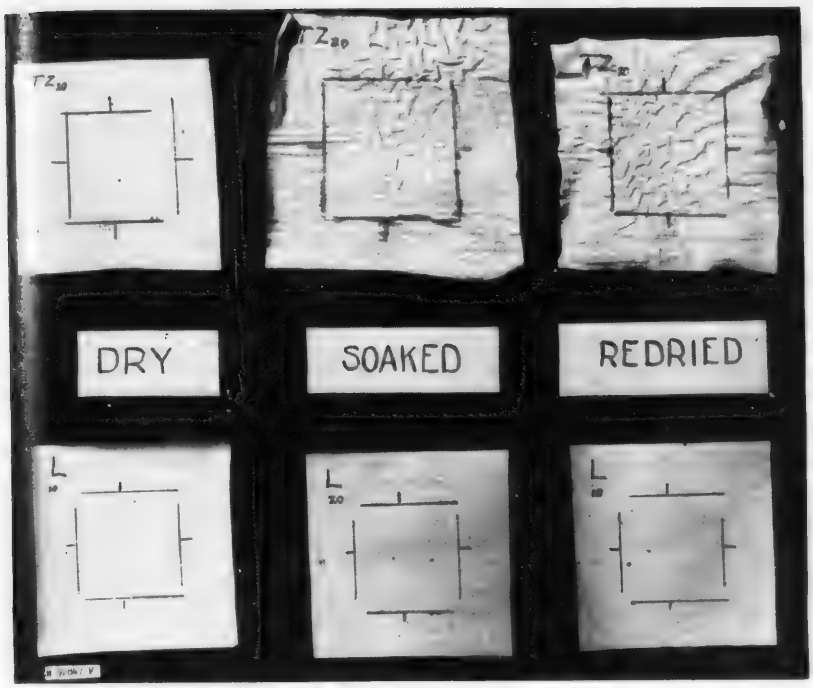
Although the 3-mil and 6-mil drawdowns made much thicker coatings than are usually spread at one time in practical painting, most of the paints dried without wrinkling and none wrinkled too seriously to be acceptable for testing. The clear liquids, however, wrinkled too badly for use. Clear liquids, therefore, were applied by brushing in a sufficient number of successive thin coats to build coatings thick enough for the purpose. Some of the paints for preliminary tests were also applied by brushing. In brush application, coating materials were always spread by stroking both longitudinally and crosswise for even application, but care was taken to see that the brushing ended with longitudinal strokes over all portions of the areas coated.

For exposure to weathering, specimens of coatings on tinplate and on siliconed paper were fastened with weather-resistant pressure tape to sheets of aluminum-painted plywood that were attached to outdoor test

Table 1.--The behavior of five kinds of films when soaked continuously in distilled water at 69.5° F. for periods of time up to 49 days

The films were 1.5 by 2.5 inches in size, of the thickness indicated below, and were 9 days old when they were stripped from gummed-paper substrates and submerged under distilled water. Negative values for swelling after redrying mean that the film shrank to less than the area before immersion.

Number of days immersed in water	Thinner films: Water absorbed (A)	Thinner films: Swelling (Increase in area) In water (ΔQ)	Thinner films: Swelling (Increase in area) Redried (ΔQ¹)	Thinner films: Solubility (Leached out by water) (S)	Thicker films: Water absorbed (A)	Thicker films: Swelling (Increase in area) In water (ΔQ)	Thicker films: Swelling (Increase in area) Redried (ΔQ¹)	Thicker films: Solubility (Leached out by water) (S)
	Milligrams	Percent	Percent	Milligrams	Milligrams	Percent	Percent	Milligrams
Raw linseed oil containing lead-manganese drier								
	Thickness 3.4 mils, initial weight 195.5 milligrams				**Thickness 6.5 mils, initial weight 371.4 milligrams**			
3	23	5	-0.5	4.7	34	4	-1.8	7.2
6	19	4	-1.0	4.7	46	9	+1.4	13.1
12	27	4	-1.4	9.7	48	6	- .9	13.7
20	45	5	-2.5	12.5	65	6	-1.1	18.5
32	149	12	-1.8	22.8	137	14	+1.1	18.1
49	148	9	.....	33.8	280	18	.....	38.9
Paint L, p/nv 0.30 (white lead paint)								
	Thickness 2.8 mils, initial weight 468.4 milligrams				**Thickness 6.2 mils, initial weight 1034 milligrams**			
3	27	10	.5	6.8	35	5	- .6	13.0
6	37	17	2.1	7.8	46	7	- .2	13.9
12	50	19	3.3	9.9	61	10	+ .3	18.5
20	57	22	4.3	12.2	73	11	+ .8	22.7
32	64	25	5.7	12.3	78	12	+ .8	23.4
49	74	24	6.0	14.1	90	12	+ .9	21.8
Paint T_{L20}, p/nv 0.30 (anatase titanium dioxide paint)								
	Thickness 2.1 mils, initial weight 141.6 milligrams				**Thickness 4.9 mils, initial weight 705.5 milligrams**			
3	59	20	+1.8	6.2	72	11	- .7	7.1
6	87	35	+4.2	7.6	114	17	+ .5	9.4
12	92	39	+6.0	11.6	152	22	+1.4	14.5
20	96	43	+3.1	14.9	158	21	+2.0	19.9
32	95	40	+ .4	21.2	177	21	+2.8	23.5
49	79	28	-2.9	30.6	158	20	+5.0	34.1
Paint Z, p/nv 0.30 (zinc oxide paint)								
	Thickness 2.5 mils, initial weight 365.2 milligrams				**Thickness 5.6 mils, initial weight 811.2 milligrams**			
3	59	70	25	10.1	284	47	16	12.7
6	.....	.....	.....	.....	400	68	26	17.7
12	.....	.....	.....	.....	416	68	25	20.3
20	.....	.....	.....	.....	362	61	23	26.0
32	.....	.....	.....	.....	342	58	21	29.9
49	.....	.....	.....	.....	365	59	23	35.0
Paint $TL_{20}Z_{20}$, p/nv 0.30 (titanium-lead-zinc paint)								
	Thickness 12.9 mils, initial weight 352.7 milligrams				**Thickness 6.5 mils, initial weight 785.0 milligrams**			
3	140	38	11	8.2	239	28	8	8.6
6	143	42	13	9.4	317	36	13	12.0
12	152	42	11	12.2	432	46	18	17.1
20	165	46	13	13.8	425	41	16	21.6
32	180	46	12	17.0	430	40	16	24.1
49	169	45	11	19.3	478	40	16	29.8



Effects of soaking in water and then redrying on free films of two different kinds of paint. The three films in the top row were of titanium-zinc paint (TZ_{20}, p/nv 0.30), the three on the bottom row were of pure white lead paint (L, p/nv 0.30). The two films in the left-hand column were dry and show the markings in drawing ink between which length and width were measured accurately with a traveling microscope. The two films in the center column had just been taken from water after soaking for three days and were still thoroughly wet. The two films in the right-hand column had been soaked in water and had then been allowed to dry out again. The rumpled films were flattened out for measurement by sandwiching them between sheets of glass.

racks facing south and sloped back at 45° from the vertical.

For exposure to artificial weathering, one set of specimens consisting of five commercial and five laboratory-made paints spread on gummed paper and on siliconed paper were exposed continuously to ultraviolet light from a flaming carbon arc covered by a globe of Corex D glass (Atlas Weatherometer) in complete dryness, that is, without usé of water spray at any time. Samples were taken for test after 400, 800, and 1,600 kilowatt-hours' exposure. The results with this run, in which water-soluble products were allowed to accumulate in the films until the immersion tests, suggested that light without moisture fails to effect the visible changes in paint that are reasonably representative of natural weathering. It was therefore decided to use the water spray in the weathering machine after equipping the spray with special nozzles that produced a fine mist rather than jets of water impinging forcefully on the paint coating. The mist deposited water gently on the surfaces in sufficient quantity to wet the surfaces thoroughly and then to drain down over the specimens and drip copiously from the bottom edges. The specimens were sprayed in that way about three times every hour. Loss of soluble ingredients by such leaching was measured by weighing specimens of coated tinplate before exposure and after periods of 400, 800, and 1,200 kilowatt-hours of exposure. Specimens of the coatings on gummed paper exposed simultaneously were then used for stripping films for measurements of water absorption and swelling. There was, however, further loss of soluble ingredients from the free films during the immersion tests.

The usual procedure with specimens on gummed paper was as follows: Ten days after the coatings had been spread the specimens were trimmed to $3\frac{1}{2}$ inches by 8 inches, as already described. Then a 2-inch length was cut off for testing before weathering. The 6-inch specimens remaining were mounted in the weathering machine and exposed for 400 kilowatt-hours (about 120 hours), after which another 2-inch length was cut off for testing. A third 2-inch length was cut off after 800 kilowatt-hours of weathering, and the remainder was available for testing after 1,200 kilowatt-hours, provided the coating was able to withstand that much weathering without cracking too seriously to be stripped and tested.

Free films, after being stripped from the substrate, were cut into test specimens either 2 inches by 2 inches in size (for the first run) or $1\frac{1}{2}$ inches by $2\frac{1}{2}$ inches in size. It was sometimes necessary to depart from the preferred dimensions when very soft young coatings or unusually brittle weathered coatings were torn or cracked in stripping or became cracked in weathering. As a rule, the $1\frac{1}{2}$-inch dimension was the direction of stroking with brush or doctor blade during application and is therefore called the length of the specimen in this report. If the direction of stroking lay otherwise than parallel to the $1\frac{1}{2}$-inch dimension, the direction was marked on the specimen with black drawing ink. Suitable reference marks were then ruled on the specimens in drawing ink to record two places, approximately 1 inch apart along the length and to points approximately 1 inch apart along the width, between which length and width could be measured exactly before and after immersion in water. The specimens were then placed in a desiccator over calcium chloride for at least 24 hours to dry them thoroughly.

The dried specimens were weighed with a chainomatic analytical balance. They were then sandwiched between $1\frac{1}{2}$- by 3-inch microscope slides to hold them flat while the length and width between reference marks were measured precisely with a traveling microscope. The lightest specimens weighed more than 0.12 gram, and the heaviest no more than 1.2 grams; weights were recorded to 0.1 milligram. Length and width were measured to 0.001 inch. Specimens were then submerged in distilled water held at 69.5° F. in a thermostat. As a rule, one 3-mil and one 6-mil film of the same kind of paint were immersed in 300 ml. of water. Paints of different kinds were immersed in separate dishes because the water comes to a pH characteristic of the kind of paint and the absorption and swelling vary with change in pH. Submerged films were weighted down beneath pads of coarsely woven spun-glass cloth to keep some of them from curling too seriously.

Except when otherwise stated, films were immersed for 72 hours, after which they were removed, sandwiched between microscope slides while still thoroughly wet, and the length and width were then remeasured with the traveling microscope. The wet films were then pressed lightly between pieces of dry blotting paper or of paper toweling to remove free water from the surfaces and reweighed as rapidly as possible, always well within 1 minute after blotting, with the chainomatic balance. The films were then allowed to dry in the laboratory for 2 or 3 hours and were then placed

in a desiccator over calcium chloride for at least 30 hours. The films were then weighed for the third time and, when the data were desired, the length and width were measured for a third time.

There was, of course, an experimental uncertainty in the second weighings while the swollen films were still wet owing to the fact that water was being lost by evaporation during progress of the weighings. A tedious procedure leading to a different end-point has been proposed (*21*) for dealing with this difficulty, but the method used, which is similar to those of other careful workers (*17*) was considered preferable because the uncertainty was found to be a negligibly small fraction of the differences among paints.

The difference between the first and the last weighing of a film gave the weight of water-soluble ingredients extracted during the period of immersion in water, represented hereafter by S. The difference between the second and the third weighing gave the weight of water absorbed by the film and still retained after loss of the water-soluble ingredients, represented hereafter by A. The swelling in length, ΔL, and in width, ΔB, was obtained from the differences between the first and the second measurements of those dimensions. The increase in area of the marked portion of the film is represented by ΔQ. On redrying, most films shrank only part of the way back to their initial dimensions.

Preliminary Tests

1. Table 1 shows that free films of linseed oil and oil paints when continuously submerged in distilled water for 49 days undergo changes all the time and fail to reach a condition of equilibrium. The five coating materials were selected to represent widely different behavior. For each material two large specimens on gummed paper were prepared, one applied with the 3-mil and the other with the 6-mil doctor blade except for the clear linseed oil, which was applied by brushing. After 8 days for hardening, six small specimens were cut from each large specimen, marked, and dehydrated over calcium chloride. On the ninth day they were weighed and measured, and each set of six matched specimens was submerged in its own dish of distilled water held at 69.5° F. At each of the prescribed periods of immersion recorded in table 1, one specimen was drawn from each matched set to be weighed and measured while wet, redried over calcium chloride, and weighed and measured again.

None of the films ever reached a long period of constancy in weight and dimensions. The general course of events was a steady gain in absorption of water and swelling until maxima were reached, after which absorption and swelling declined. The 6-mil films of the two paints that contained zinc oxide attained their maxima relatively early, perhaps at 12 days, although the thinner film of titanium-lead-zinc paint continued to absorb and swell until the thirty-second day. The other paints and the clear linseed oil did not reach their maxima before the twentieth to thirty-second day. Some of them gave the highest readings on the forty-ninth and last day of test, but it may be presumed that on still longer immersion they, too, would begin to decline. On the other hand, the loss of water-soluble ingredients by films of all kinds and thicknesses continued steadily upward throughout the 49 days of test except for the pure white lead paint, for which the solubility was nearly constant from the twentieth to the forty-ninth day. When redried after immersion, the two paints containing zinc oxide retained a large part of the great increase in area they had experienced during immersion. Paints and oil that did not swell so much in water, on redrying, shrank more nearly, though seldom quite, to their original dimension; occasionally a zinc-free paint and frequently a clear oil film shrank back to less than its initial length and width (indicated in table 1 by minus signs). Loss of water-soluble ingredients readily accounts for such shrinkage.

The course of the absorption, swelling, and leaching in water suggests no one period of immersion that is more significant than any other. For the rest of this study a soaking period of 72 hours was selected because it has been used by some previous workers, is short enough for reasonable convenience in the conduct of the tests, and is not so long as to permit unduly serious chemical changes in the films while they are being tested.

2. The temperature of the water in which paint films are immersed markedly affects their absorption, swelling, and solubility, as is shown

Table 2.--Effect of temperature of soaking water on absorption, swelling, and solubility of films

The films were 2 by 2 inches in size, of the thickness indicated below, and were nearly 3 months old (stored indoors in a dry, dark place) when they were stripped from the substrates and tested by immersion in water for 72 hours.

Temperature of soaking water	Water absorbed (A)	Swelling (Increase in area) (ΔQ)	Solubility (Leached out by water) (S)
°F.	Milligrams	Percent	Milligrams
Paint L, p/nv 0.30 (white lead paint); thickness 6.8 mils, initial weight 1,207 milligrams			
33 to 36	9	1.3	2.2
72 to 75	20	2.2	6.8
88 to 98	34	2.6	12.6
Paint TZ_{20}, p/nv 0.30 (titanium-zinc paint); thickness 7.7 mils, initial weight 878 milligrams			
33 to 36	103	7	6.5
72 to 75	369	34	18.1
88 to 98	519	78	48.5

in table 2. In water at 88° to 98° F. (near body temperature) the changes in films of titanium-zinc paint were 5 to 10 times as great as they were in water at 33° to 36° F. (near freezing). For pure white lead paint, which is a more resistant paint to water, the effect of temperature was somewhat less marked, but the absorption, swelling, and solubility at the highest temperature were still 2 to 6 times those at the lowest temperature. It was therefore necessary in all subsequent tests to hold the water at constant temperature during immersion tests by keeping the dishes in a closely controlled water thermostat.

3. The degree of acidity or alkalinity, measured customarily in terms of pH, and the presence of soluble salts in the water in which paint films are immersed, greatly modify the absorption of water, swelling, and solubility of paints that contain zinc oxide, although the effects are less on paints that contain much white lead. Table 3 records tests made with films of pure white lead paint and of a titanium-zinc paint immersed in solutions buffered with mixtures of citric acid and sodium phosphate to hold the pH at 6.0, 7.0, and 8.0 with approximately 0.03 moles of solute per liter, and at pH 7.0 with double that concentration of solute. With white lead paint the absorption of water was slightly greater at pH 7.0 than at pH 6.0 or 8.0, but there was little or no effect on the swelling; solubility was very low at pH 7.0 and increased with pH, but it was still moderate at pH 8.0. A small quantity of buffer salts remained in the films after they were removed from the solutions and dried, the amount of which was determined by soaking the films in distilled water for 24 hours and then drying and weighing them again.

The films of TZ paint were seriously affected at pH 7.0 and 8.0 in a manner suggesting break-down of the gel structure. The films soon became softened, the surfaces became tacky enough to stick together where they came in contact, and there was obvious dislodgment of both pigment and vehicle from the surfaces. It was found possible to measure absorption and swelling only for the first 19 hours of immersion at pH 7.0 or 8.0. Swelling apparently did not vary greatly with pH, but the absorption of water varied greatly but unsystematically. Solubility increased greatly with pH except for an anomaly in the most concentrated buffer solution of pH 7.0, where adequate differentiation between leaching of film substance and retention of buffer salts in the film proved experimentally diffi-

Table 3.—Effect of pH (degree of acidity or alkalinity) of soaking water on absorption, swelling, and solubility of films

The films were 2 by 2 inches in size, of the thickness indicated below, and were nearly 3 months old (stored indoors in a dry, dark place) when they were stripped from the substrates and tested by immersion in buffer solutions (citric acid and sodium phosphate) of the pH and concentration indicated; temperature 72° to 75° F.

Soaking solution		Water absorbed (A)		Swelling (ΔQ)		Solubility (leached out by solution) (S)	Buffer salts absorbed by film
pH	Concentration of buffer salts	In 19 hours	In 72 hours	In 19 hours	In 72 hours		
	Moles per liter	Milligrams	Milligrams	Percent	Percent	Milligrams	Milligrams
Paint L, p/nv 0.30 (white lead paint); thickness 6.0 mils, weight 1,067 milligrams							
6.0	0.030	11	29	1.9	2.9	1.2	3.1
7.0	.033	16	33	1.6	3.3	8.5	3.7
7.0	.066	14	43	1.7	2.4	9.8	3.2
8.0	.036	6	41	1.9	3.6	13.4	3.2
Paint TZ_{20}, p/nv 0.30 (titanium-zinc paint); thickness 4.7 mils, weight 534 milligrams							
6.0	.030	141	242	22	33.2	40	3.7
7.0	.033	90	(1)	22	(1)	71	.....
7.0	.066	218	(1)	28	(1)	0	39.4
8.0	.036	184	(1)	27	(1)	114	16.2

[1] In solutions of pH 7.0 or pH 8.0, films of TZ paint after 19 hours acquired such soft and tacky surfaces that they were no longer manageable for weighing and measuring while still wet.

Table 4.—Loss in weight and shrinkage of free films of five kinds when allowed to stand 53 days in the laboratory in preparation for tests reported in table 5

The films were 1.5 by 2.5 inches in size, of the thickness indicated, and were 7 days old when stripped from gummed paper substrates, marked, weighed, and measured, after which they stood 53 days before making final weighings and measurements. (Intermediate observations were made but are not tabulated.)

Kind of film	Thickness of film	Initial weight of film	Loss in weight	Shrinkage in length	Shrinkage in width	Shrinkage in area
	Mils	Milligrams	Milligrams	Percent	Percent	Percent
Linseed oil and drier	3.4	192	4.9	1.9	2.2	4.1
	6.1	347	7.5	1.6	1.4	3.0
Paint L, p/nv 0.30	2.9	482	3.6	.9	.9	1.8
	6.1	1,013	5.2	1.2	1.4	2.6
Paint T_{420}, p/nv 0.30	2.1	312	5.7	2.0	1.8	3.8
	4.8	696	9.5	2.7	2.5	5.3
Paint Z, p/nv 0.30	2.2	326	1.9	.4	.7	1.1
	5.5	800	3.7	1.1	1.1	2.2
Paint $TL_{20}Z_{20}$, p/nv 0.30	2.9	349	2.9	.8	1.2	2.0
	6.6	782	.2	.6	1.1	1.7

cult. The quantity of buffer salts retained in the film after removal and drying was much greater at pH 7.0 and pH 8.0 than at pH 6.0.

In another experiment a film of the TZ paint of initial weight of 483 milligrams was immersed in distilled water for 23 hours, when the absorption was found to be 117.3 milligrams (uncorrected for loss by leaching), and the swelling was 20.7 percent. While still wet, the film was then immersed for 24 hours in water kept saturated with sodium chloride. The film lost all of its absorbed water together with a loss of 12.9 milligrams by leaching while in the saturated salt solution, but it shrank back only part way, to a net gain over the original area of 4.3 percent.

Only a few exploratory tests have been made so far on the composition of the soaking water after films of paints have been soaked in distilled water for 3 days. It has been tentatively observed, however, that the soaking water after contact with pure white lead paint comes to pH 7.2, approximately, and contains only enough soluble lead compounds to be slightly discolored by hydrogen sulfide without precipitating an observable amount of lead sulfide. The soaking water from pure zinc oxide paint comes to pH 5.7, approximately, and contains enough soluble zinc compounds to yield a copious precipitation of zinc sulfide with hydrogen sulfide. The soaking water from pure titanium dioxide paint comes to a pH lower than 5.2 and is unaffected by hydrogen sulfide.

The pronounced effect of pH on the behavior of many paints made it advisable to use only distilled water for subsequent soaking tests and to avoid immersing films of more than one kind of paint in any one dish of distilled water.

4. To observe the rate at which films of coating materials change while kept under ordinary room conditions, the five materials reported in tables 4 and 5 were applied to gummed paper, each in nominal 3-mil and in nominal 6-mil thickness. Films were stripped, cut to size, and marked after 7 days of drying, which was about the earliest age at which all of them were hardened enough to

Table 5.--Effect of aging during storage indoors on the absorption of water, swelling, recovery after redrying, and solubility of films of five kinds of coating materials

The films were 1.5 by 2.5 inches in size, of the thickness indicated, were stripped from gummed paper 7 days after application, and were then stored for the additional times recorded in the first column before testing by immersion in distilled water at 69.5° F. for 72 hours. Negative values for swelling after redrying mean that the film shrank to less than the area before immersion.

Time in storage after stripping before test by immersion	Thinner films: Water absorbed (A)	Thinner films: Swelling (Increase in area) In water (ΔQ)	Thinner films: Swelling (Increase in area) Redried (ΔQ^1)	Thinner films: Solubility (Leached out by water) (S)	Thicker films: Water absorbed (A)	Thicker films: Swelling (Increase in area) In water (ΔQ)	Thicker films: Swelling (Increase in area) Redried (ΔQ^1)	Thicker films: Solubility (Leached out by water) (S)
Days	Milligrams	Percent	Percent	Milligrams	Milligrams	Percent	Percent	Milligrams
Linseed oil containing lead-manganese drier								
Thickness 3.4 mils, initial weight 192 milligrams					Thickness 6.1 mils, initial weight 353 milligrams			
0	28	5	-1.5	7.2	37	5	-1.4	10.0
5	.....	.....	.....	.....	25	5	- .4	10.6
12	20	3	- .7	5.8	22	4	-1.9	8.3
22	17	4	-1.3	6.7	27	3	-1.9	10.5
33	.....	.....	.....	.....	28	3	-1.8	11.9
53	81	10	- .9	10.8	30	5	-2.4	12.2
Paint L, p/nv 0.30 (white lead paint)								
Thickness 2.9 mils, initial weight 461 milligrams					Thickness 6.1 mils, initial weight 1023 milligrams			
0	27	9	+ .3	6.7	33	5	- .6	9.7
5	20	6	+ .4	7.1	30	4	- .8	10.8
12	19	7	0.	6.1	28	4	- .7	11.9
22	15	6	- .2	6.3	25	3	- .7	12.6
33	14	5	- .7	7.4	27	3	- .8	12.8
53	15	4	-1.1	6.4	24	3	- .8	12.3
Paint $T_4 20$, p/nv 0.30 (anatase titanium dioxide paint)								
Thickness 2.1 mils, initial weight 309 milligrams					Thickness 4.8 mils, initial weight 706 milligrams			
0	52	19	+1.3	7.0	74	10	- .6	10.0
5	47	18	+ .8	2.6	67	10	- .8	11.1
12	44	16	+1.1	5.3	66	9	- .3	10.3
22	39	15	+ .7	6.4	67	9	- .2	12.6
33	35	13	0	7.	64	9	- .5	12.1
53	32	10	- .6	8	103	10	0	17.1
Paint Z, p/nv 0.30 (zinc oxide paint)								
Thickness 2.2 mils, initial weight 316 milligrams					Thickness 5.5 mils, initial weight 795 milligrams			
0	68	40	3		332	58	25	14.7
5	56	38	4		283	55	24	13.9
12	62	38	7		251	45	17	11.1
22	61	36	7		230	41	17	12.4
33	61	34	7		230	40	16	9.0
53	61	31	6		217	37	16	10.2
Paint $TL_{20}Z_{20}$, p/nv 0.30 (titanium-lead-zinc paint)								
Thickness 2.9 mils, initial weight 351 milligrams					Thickness 6.6 mils, initial weight 791 milligrams			
0	167	47	16	10.5	245	31	11	17.3
5	137	42	14	7.0	203	24	7	12.6
12	125	34	10	4.8	178	18	5	10.9
22	99	28	8	4.4	160	18	6	10.1
33	88	26	7	5.4	144	16	4	9.7
53	79	24	8	4.9	124	15	5	10.0

le processed without damage. Six matched specimens for each material nd thickness were prepared, weighed nd measured, and then allowed to est on a table top near a closed indow of the laboratory with northrn exposure. From each set of atched specimens one was taken mmediately and one after 5, 12, 22, 33, and 53 days, respectively, for test by immersion in distilled water for 3 days.

All films except the 6-mil films of paint $TL_{20}Z_{20}$ lost in weight and shrank progressively throughout the period of storage before immersion in water. The 6-mil films of paint $TL_{20}Z_{20}$ gained slightly in weight for 33 days and swelled in area for 5 days before they began to decrease in weight and dimensions. All of the changes, however, were small when compared with the changes most paints undergo when immersed in water. Table 4 records the changes at the end of the 53-day storage period. Differences among the coating mate-

Table 6.--Absorption of water by free films of different coating materials during 72-hour immersion in distilled water at 69.5° F., both before and after exposure of the films to artificial weathering, expressed in percentage of the weight of linseed oil in the films

The films were 1.5 by 2.5 inches in size, of the thickness indicated, and were prepared on gummed paper. After 10 days for hardening, samples were stripped for the immersion test before weathering and the rest were exposed to ultraviolet light and periodic water spray in a weathering machine. Further samples were stripped for immersion tests after 400, 800, and 1,200 kilowatt hours of exposure, respectively. The weight of linseed oil in a 1.5- by 2.5-inch film 3.0 mils thick, W_o, is 171 milligrams; in a paint of p/nv 0.30 it is 120 milligrams, p/nv 0.36 it is 109 milligrams, p/nv 0.40 it is 102 milligrams.

Coating material	Pigment volume in paint p/nv	Thinner films: Initial thickness	Thinner films: Absorption of water, A/Wo, after exposure for indicated number of kilowatt-hours: 0	400	800	1,200	Thicker films: Initial thickness	Thicker films: Absorption of water, A/Wo, after exposure for indicated number of kilowatt-hours: 0	400	800	1,200
		Mils	Percent of the oil in film, by weight				Mils	Percent of the oil in film by weight			
Group 1 - Unpigmented coating materials											
Raw linseed oil	0	4.8	32	.....	62	42	6.5	21	11	12	12
Bodied linseed, Z3	0	6.3	9	5	16	22	15.5	4	5	6	8
Bodied linseed, Z6	0	6.4	7	11	16	33	16.0	3	4	6	8
Alkyd resin	0	4.1	8	6	10	13	7.6	6	4	5	7
Group 2 - Linseed oil paints free from zinc oxide											
Magnesium silicate	0.30	3.4	125	15	.....	.....	7.6	63	15	19	23
Calcium carbonate	.30	2.8	83	25	13	13	6.5	126	24	10	9
L	.30	3.0	18	26	29	28	6.4	12	11	13	15
L	.36	2.4	20	47	25	40	4.9	12	20	29	27
TL40	.30	3.1	74	13	13	.....	6.5	44	13	9	7
TL40	.40	2.6	58	22	25	.....	5.6	34	20	13	14
T_{420}	.09	3.1	26	23	18	.....	4.2	20	32	12	10
T_{420}	.30	2.1	49	15	16	.....	4.7	27	6	7	10
Average for group 2			57	23	20			42	18	14	14
Group 3 - Alkyd-resin paints											
T(are)	.30	3.4	44	18	12	9	4.6	42	23	19	17
T(are)	.36	2.9	57	32	13	10	3.9	73	32	27	12
T(are)	..40	2.9	79	29	14	13	4.3	79	39	26	13
Group 4 - Linseed oil paints containing zinc oxide and of p/nv 0.30											
Z	.30	2.6	149	114	67	67	5.9	96	40	25	20
LZ37	.30	3.2	100	69	.....	.....	6.6	70	32	21	23
$TL_{50}Z_{30}$	.30	3.2	130	68	43	28	6.6	84	40	20	15
$TL_{30}Z_{25}$	.30	3.2	130	81	54	62	6.8	78	39	22	19
$TL_{20}Z_{20}$	.30	3.3	127	61	41	37	6.7	86	37	22	16
$TL_{10}Z_{10}$	.30	3.3	154	59	51	48	6.3	96	36	24	16
TZ_{20}	.30	3.3	145	90	75	71	6.8	97	46	43	25
Average for group 4			134	77	55	52		87	39	25	19
Group 5 - Linseed oil paints containing zinc oxide and of p/nv 0.30 or 0.40											
$TL_{30}Z_{25}$	.36	2.6	141	85	70	.....	5.6	69	47	26	21
$TL_{20}Z_{20}$	.36	2.7	148	79	51	46	5.6	86	49	26	24
$TL_{10}Z_{10}$	.36	2.9	142	62	49	45	6.1	82	39	23	17
TZ_{20}	.36	3.0	178	82	70	61	5.9	106	59	46	43
TZ_{20}	.40	3.0	173	81	67	.....	5.8	113	57	44	49
Average for group 5			156	78	61	51		91	50	33	31
Group 6 - Commercial paints											
No. 1 - TL_7Z_{23}	.35	2.9	137	74	56	50	6.1	87	41	28	28
No. 2 - $(TL_{23}Z_{18})_{134}$	.31	3.2	138	62	45	42	6.2	79	30	21	22
No. 3 - $(TZ_{19})_{126}$	.30	2.8	118	90	82	72	5.7	100	48	35	36
No. 4 - $(TZ_{16})_{122}$	.38	2.8	145	103	88	89	6.0	155	81	61	61
No. 5 - T_{139}(re)	.31	1.8	93	42	39	46	3.9	.....	33	26	29

rials were relatively small. In another preliminary test it was found that films of paint L and of paint TZ_{20} were still losing weight very slowly after 8 months in storage. Both of these films increased slightly in weight for about 50 hours after they were applied and then began to fall off steadily, but the loss after 8 months was only 27 milligrams for paint L and 17 milligrams for paint TZ_{20}.

Table 5 records the results of immersion tests made with the films after different periods of storage up to 53 days after stripping from the substrate (60 days after applying the coatings). Absorption of water and swelling diminished steadily for at least the first 3 weeks. After that time films of clear linseed oil and the thicker film of titanium dioxide paint began to increase again in absorption and swelling, whereas the other films continued to decline. The solubility of the films and the dimensional changes on redrying after immersion did not change very much for any of the films, although they diminished slightly with age for the films of zinc oxide and of titanium-lead-zinc paint. On the whole, differences among the paints at any age were much larger than the differences

Table 7.--Swelling (increase in surface area) of free films of different coating materials during 72-hour immersion in distilled water at 69.5° F., both before and after exposure of the films to artificial weathering

The measurements of swelling were made on the same films and at the same times as the measurements of absorption of water recorded in table 6. By way of comparison, flat-grain surfaces of southern yellow pine boards shrink 6.2 percent (practically all across the grain) in drying from the green condition to 6 percent moisture content. Most other softwoods shrink less than that.

Coating material	Pigment volume in paint p/nv	Swelling (increase in area) after exposure for indicated number of kilowatt-hours							
		Thinner films				Thicker films			
		0	400	800	1,200	0	400	800	1,200
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Group 1 - Unpigmented coating materials									
Raw linseed oil	0	22	.....	13	10	12	3	4	6
Bodied linseed, Z3	0	11	3	4	8	3	3	3	3
Bodied linseed, Z6	0	6	3	3	10	2	2	3	3
Alkyd resin	0	5	4	3	3	4	3	2	3
Group 2 - Linseed oil paints free from zinc oxide									
Magnesium silicate	0.30	27	4	.....	.....	16	3	8	10
Calcium carbonate	.30	26	11	3	4	54	9	2	2
L	.30	8	2	1	1	5	2	2	2
L	.36	8	3	2	1	4	2	2	2
TL_{40}	.30	27	4	3	.....	15	4	2	2
TL_{40}	.40	18	6	4	.....	8	6	3	4
T_{420}	.09	13	8	7	.....	13	7	6	4
T_{420}	.30	18	3	3	.....	10	2	1	1
Average for group 2		18	5	3		16	4	3	3
Group 3 - Alkyd-resin paints									
T(are)	.30	9	6	3	3	10	5	4	3
T(are)	.36	12	6	3	3	10	4	4	3
T(are)	.40	12	4	2	2	9	4	4	3
Group 4 - Linseed oil paints containing zinc oxide and of p/nv 0.30									
Z	.30	70	43	21	16	33	13	8	6
LZ_{37}	.30	42	29	.....	.....	27	11	9	7
$TL_{50}Z_{30}$	.30	49	28	20	16	30	11	6	6
$TL_{30}Z_{25}$	.30	49	32	18	19	27	12	7	9
$TL_{20}Z_{20}$	.30	40	19	13	13	26	9	6	4
$TL_{10}Z_{10}$	.30	47	17	16	12	29	9	6	5
TZ_{20}	.30	57	35	29	25	40	16	11	10
Average for group 4		51	29	19	17	30	12	8	7
Group 5 - Linseed oil paints containing zinc oxide and of p/nv 0.30 or 0.40									
$TL_{30}Z_{25}$	.36	46	27	13	.....	18	12	7	6
$TL_{20}Z_{20}$	.36	45	25	15	14	22	12	7	7
$TL_{10}Z_{10}$	.36	38	18	12	11	19	8	5	4
TZ_{20}	.36	56	31	23	21	36	18	15	15
TZ_{20}	.40	53	27	19	.....	30	20	14	17
Average for group 5		48	26	16	16	25	14	10	10
Group 6 - Commercial paints									
No. 1 - $TL_7 Z_{23}$	.35	38	24	17	14	24	10	18	9
No. 2 - $(TL_{23}Z_{18})_{134}$	.31	35	18	11	10	19	8	5	5
No. 3 - $(TZ_{19})_{126}$	.30	26	20	17	21	17	8	6	7
No. 4 - $(TZ_{16})_{122}$	.38	55	38	29	27	49	26	22	19
No. 5 - T139(re)	.31	3	2	1	1	.....	1	1	0.3

Table 8.--Swelling efficiency of water for the free films reported in tables 6 and 7

The swelling efficiency is the swelling recorded in table 7 divided by the absorption of water per unit weight of oil in the film recorded in table 6, that is, $\Delta Q \div A/W_o$.

Coating material or group of materials as classified in tables 6 and 7	Average swelling efficiency for the group after exposure for indicated number of kilowatt-hours							
	Thinner films				Thicker films			
	0	400	800	1,200	0	400	800	1,200
	Percent				Percent			
Group 1 - Unpigmented materials	80	61	27	29	72	48	46	43
Group 4 - Zinc-containing paints of p/nv 0.30	39	39	35	35	37	31	31	35
Group 5 - Zinc-containing paints of p/nv 0.36 or 0.40	31	33	27	29	27	27	29	30
Group 6 - Commercial zinc-containing paints	28	30	27	27	25	25	25	27
Group 2 - Zinc-free paints other than white lead	34	30	23	28	38	29	31	29
Group 3 - Alkyd-resin paints	19	22	21	26	16	14	17	22
White lead paints, L p/nv 0.30 and 0.36	43	9	6	5	38	18	13	15
Commercial paint No. 5 ("breather type")	3	4	2	2	....	3	4	1

brought about by aging of any one kind of paint. For the subsequent studies, films were allowed to harden for 10 days after application before they were stripped from the substrate and were then submitted to immersion tests within 3 days.

Tests of 32 Oils and Paints Before and After Artificial Weathering

Large specimens of the 32 coating materials on substrates of gummed paper were prepared, each material in nominal 3-mil and 6-mil thicknesses. After 10 days for hardening, a small sample was cut from each large specimen to be stripped and tested immediately by immersion in water. The remaining portions of the large specimens were placed at once in the artificial weathering machine, operated with periodic spraying with water. Each large specimen was further sampled for stripping and testing after 400, after 800, and after 1,200 kilowatt-hours of exposure (approximately 5, 10, and 15 days of continuous operation). A second complete set of specimens spread on tinplate instead of gummed paper was exposed in the weathering machine at the same time in order to determine the weight of soluble material leached from each specimen by the water spray during the course of the artificial weathering.

Absorption of Water: The absorption of distilled water on 72-hour soaking of the free films before and after each stage of artificial weathering is reported in table 6. The weight of water absorbed by each free film is expressed in percentage of the weight of linseed oil in the film, that is, $100A/W_o$, where W_o is the weight of oil in the film. That is considered a more significant basis for comparing the different paints and film thicknesses than the absorption in milligrams of water, A, because absorption and swelling are believed to reside primarily in the oil in the film. It would be very misleading, of course, to express the absorption in percentage of the total weight of film in view of the great variation in specific gravity of different pigments. Thus the weight of a free film 1.5 inches long, 2.5 inches wide, and 3 mils thick is approximately 171 milligrams for unpigmented linseed oil, 270 milligrams for calcium carbonate paint of p/nv 0.30, and 499 milligrams for white lead paint of p/nv 0. 30.

All of the free films tested absorbed distilled water in significant quantity. For all of the paints in which there were pigments, the newly prepared and unweathered films absorbed much more water than the artificially weathered films did. The first 400 kilowatt-hours of weathering usually effected greater reduction in swelling than the next 400 kilowatt-hours did, but the last 400 kilowatt-hours produced so little further change as to suggest that a minimum had been reached. Some films, in fact, absorbed more water after 1,200 than after 800 kilowatt-hours of exposure. Films of clear oils without pigments, with the possible exception of the bodied linseed oil of viscosity Z6, passed through a minimum of absorption after 400 kilowatt-hours and usually absorbed more water after 1,200 kilowatt-hours than they did before exposure to weathering.

The bodied linseed oils initially were much less absorptive than the raw linseed oil, but after weathering the differences became small. The alkyd resin was only slightly less absorptive than the bodied linseed oil of viscosity Z6.

Paint made with magnesium silicate in raw linseed oil absorbed more water than the unpigmented oil did, especially so before the films were weathered. On the other hand, the calcium carbonate paint, although high in absorption at the outset, became less absorptive than unpigmented oil after weathering. Pure titanium dioxide paint, T_{420}, was initially slightly more absorptive and, after weathering, slightly less absorptive than raw linseed oil.

Pure white lead paint, L, at the outset had a lower absorption than any other paint and a lower absorption than raw linseed oil. Weathering produced relatively little change in the absorption of pure white lead paint, so that, in the end, it still remained less absorptive or, in the thicker film, only slightly more absorptive than raw linseed oil.

Zinc oxide, on the other hand, whether the sole pigment in a paint or present to the extent of as little as 10 percent of the total pigment by volume, very greatly stimulated absorption of water by free films, particularly when the films were unweathered. Thus pure zinc oxide paint, Z, and titanium-zinc paint, TZ_{20}, absorbed about 5 times as much water initially as raw linseed oil did, and remained 2 to 4 times as absorptive after weathering. The presence of white lead along with zinc oxide usually reduced the absorptiveness somewhat, but the stimulating effect of zinc oxide was dominant over the

moderating effect of white lead even when there was 1.7 times as much white lead as zinc oxide in the paint.

Paints of pigment volume 0.36 or 0.40 usually absorbed a little more water in proportion to their oil content, although slightly less in proportion to their volume than the corresponding paints of pigment volume 0.30, despite the fact that much of the oil in the former was bodied oil, whereas all the oil in the latter was the more absorptive raw oil.

Of the five commercial paints tested, the four that contained zinc oxide proved high in absorption, comparably so with the laboratory-made paints of similar composition. The fifth commercial paint, advertised as resistant to moisture blistering, was decidedly less absorptive than the others but was more absorptive than the paints made in the laboratory with no lead or zinc pigments and alkyd-resin vehicle.

Swelling in Water: Table 7 records the swelling, ΔQ (increase in area of surface), of the free films caused by the absorption of water reported in table 6. In general, the swelling runs approximately parallel to the absorption of water, as would be expected. The relations already discussed for absorption therefore apply also to swelling, except that commercial paint No. 5 exhibited disproportionately low swelling for the amount of water it absorbed. Possible reasons for the peculiar behavior of this paint are discussed further on.

The swelling of the free paint film may well be compared with the swelling of wood on which such paints might be used. Flat-grain boards of southern yellow pine change 6.6 per

Table 9.--Solubility of free films of different coating materials during 72-hour immersion in distilled water at 69.5° F., determined while making the measurements of absorption and swelling recorded in tables 6 and 7, and expressed in percentage of the weight of linseed oil in the films

Coating material	Pigment volume in paint p/nv	Solubility in water, S/Wo, after exposure for indicated number of kilowatt-hours							
		Thinner films				Thicker films			
		0	400	800	1,200	0	400	800	1,200
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Group 1 - Unpigmented coating materials									
Raw linseed oil	0	7.0	.....	9.6	10.9	3.9	2.5	2.0	7.0
Bodied linseed, Z3	0	4.0	2.6	4.7	7.0	1.4	1.2	2.0	3.0
Bodied linseed, Z6	0	3.4	2.3	3.9	7.9	1.0	.9	1.7	2.6
Alkyd-resin	0	7.0	2.9	3.4	4.4	3.2	.8	2.1	2.3
Group 2 - Linseed oil paints free from zinc oxide									
Magnesium silicate	0.30	7.5	5.8	.....	.....	3.6	3.0	5.5	5.6
Calcium carbonate	.30	14.5	11.1	5.9	7.1	9.7	4.7	2.3	2.7
L	.30	4.7	5.8	6.6	9.0	3.3	2.7	2.8	2.9
L	.36	6.8	4.9	10.7	12.0	4.4	2.8	4.3	4.7
TL40	.30	5.4	6.6	3.3	.....	4.4	2.8	2.2	2.0
TL40	.40	6.5	9.8	5.0	.....	3.5	5.1	3.1	4.8
T420	.09	4.4	5.5	5.8	.....	4.5	4.1	5.0	3.0
T420	.30	5.5	7.7	9.3	.....	3.9	2.0	3.5	5.0
Average for group 2		6.9	7.1	6.7		4.7	3.4	3.6	3.8
Group 3 - Alkyd-resin paints									
T(are)	.30	8.3	4.8	5.6	3.9	4.2	3.5	4.5	3.2
T(are)	.36	5.6	5.3	6.0	6.8	3.2	3.0	4.3	2.9
T(are)	.40	4.9	5.3	6.2	7.0	3.2	3.3	4.5	.7
Group 4 - Linseed oil paints containing zinc oxide and of p/nv 0.30									
Z	.30	11.2	7.5	3.9	16.0	3.8	2.7	2.1	2.2
LZ37	.30	6.3	9.5	.....	.....	2.6	1.5	1.5	2.1
TL50Z30	.30	5.8	5.6	6.4	3.0	3.4	3.4	3.2	2.7
TL30Z25	.30	5.7	5.7	7.5	5.3	2.7	2.7	2.7	1.5
TL20Z20	.30	5.5	5.4	6.1	3.5	.7	1.6	3.2	2.1
TL10Z10	.30	5.1	6.4	8.6	6.6	4.0	1.8	3.2	2.2
TZ20	.30	8.2	7.0	7.8	7.0	4.8	2.5	3.7	3.1
Average for group 4		6.8	6.7	6.7	6.9	3.1	2.3	2.8	2.3
Group 5 - Linseed oil paints containing zinc oxide and of p/nv 0.36 or 0.40									
TL30Z25	.36	5.1	7.3	7.8	.....	2.8	3.9	5.0	2.0
TL20Z20	.36	4.5	7.3	10.0	8.0	4.0	3.5	3.2	3.7
TL10Z10	.36	5.4	6.6	8.7	4.5	4.2	2.5	2.9	3.0
TZ20	.36	7.1	14.9	10.9	13.2	3.0	9.7	2.9	3.6
TZ20	.40	8.0	7.3	10.5	.....	3.8	6.7	3.8	6.4
Average for group 5		6.0	8.7	9.6	8.6	3.6	5.3	3.6	3.7
Group 6 - Commercial paints									
No. 1 - TL_7Z_{23}	.35	27.5	9.1	7.8	9.6	5.1	3.5	3.3	4.2
No. 2 - $(TL_{23}Z_{18})_{134}$	.31	6.6	7.9	4.1	4.3	3.9	2.1	1.7	3.7
No. 3 - $(TZ_{19})_{126}$	.30	12.1	13.8	7.9	12.3	4.3	5.2	4.4	5.8
No. 4 - $(TZ_{16})_{122}$	.38	23.6	19.0	25.6	31.8	12.4	7.2	6.4	12.8
No. 5 - T_{139}(re)	.31	9.2	11.4	9.3	16.1	.....	6.0	6.4	6.8

cent in width (across the grain) and practically not at all in length (along the grain) between 6 percent moisture content and the green or thoroughly water-soaked condition. The moisture content of exterior lumber is seldom as low as 6 percent. The change in area is therefore 6.6 percent of the dry dimensions or 6.2 percent of the green dimensions. Most other woods used on houses swell less than southern yellow pine. Thus free films of most paints when newly prepared swell more than wood does on changing from the air-dry to the water-saturated condition. After weathering for some time, zinc-free paints usually swell less than wood does. Paints containing zinc oxide swell several times as much as wood does when the paints are new, and swell as much or more than wood does even after they have become well weathered. Of course, the coatings of paint must conform to the wood in length and width as long as the coatings remain in place, and to do so the coatings must change sufficiently in thickness to meet the required volumetric changes, a process that necessarily involves severe internal stresses in a rigid body.

To check that conclusion, dry 1/24-inch yellow-poplar veneer was painted in one case with two coats of paint L, p/nv 0.30, making a coating 3.6 mils thick when dry, and in another case with two coats of paint TZ_{20}, p/nv 0.30, making a coating 4.8 mils thick when dry. Suitable specimens were marked for measurement of length, width, and coating thickness (by observation of sharply cut edges in a microscope with micrometer eyepiece) and were then soaked in water for 2 days and remeasured while still wet. In surface area both paint coatings swelled 10 percent, chiefly across the grain of the wood, which is the expected dimensional change for thin veneer of yellow-poplar. In thickness the coating of paint L shrank 0.2 mil, but that of paint TZ_{20} swelled 2.7 mils. The result was qualitatively in agreement with the data of table 7, which give the swelling in area as 8 percent for paint L and 57 percent for paint TZ_{20} in free films about 3 mils thick after soaking 3 days. At the end of the soaking period the coating of paint TZ_{20} was beginning to form tiny blisters, but that of paint L was still entirely sound.

Among the paints reported in table 7, paints L, TL_{40}, and commercial paint No. 5 are known from past tests on laboratory blistering boxes and from experience on houses to be highly resistant to failures by blistering and peeling under conditions of so-called excessive moisture. Work reported by a large paint-industry laboratory indicates that the leadless and zincless alkyd-resin paints, T(are), are similarly resistant to such conditions. All of these paints are characterized by a low degree of swelling in water. On the other hand, all of the zinc-containing paints, which have a high degree of swelling, are known from past experience to be sensitive to moisture blistering and peeling. It may well be, then, that the degree of swelling in water is a useful measure of the ease with which a paint yields to blistering and peeling of this kind.

During the immersion tests the free films of those paints that exhibited a low degree of swelling remained flat and free from troublesome curling. Even after redrying they could be kept flat provided the absorbed water was allowed to evaporate equally rapidly from both faces of the film. In contrast, free films of paints that swelled greatly always had a marked tendency to curl, particularly near the edges of the films, and required very careful handling to straighten them out between glass microscope slides sufficiently to measure the dimensions. Such curling became still more marked during redrying. These differences in behavior correspond to the characteristic performance of the paints during the later stages of normal weathering. Once cracking sets in, paints that swell greatly also curl markedly at the cracked edges and tend toward scaling in large pieces, whereas paints of low degree of swelling, if they crack at all, usually curl very little and tend toward crumbling or flaking in tiny particles.

Extreme curling during immersion in water was exhibited by heterogeneous films made up of consecutive coats of paints of widely different swelling tendencies. Thus free films were prepared by applying in one case two coats of paint L, p/nv 0.30, followed by two coats of paint TZ_{20}, p/nv 0.30, and in the other case two coats of the TZ_{20} paint, followed by two of paint L. When the free films were soaked in distilled water for a few days, both curled into tight rolls much like rolls of wrapping paper. The two films curled in opposite directions, so that in both cases the highly swellable TZ paint was on the outside of the curled roll and in both cases the direction of last brushing of the paints during application was parallel to the axis of the roll. After the films were soaked for a week, the two layers of paint in each film began to separate and the TZ layer became wrinkled until eventually it was an easy matter to pull the two layers completely apart.

Some Paints Possess Grain: When free films swell while immersed in water, the increase in width, ΔB, usually differs from the increase in length, ΔL. (The length is always the direction in which the brush or doctor blade was last moved during application.) The ratio $\Delta B/\Delta L$ is not exactly reproducible quantitatively among different films of the same kind or even in different sections cut from the same large film; slight variations in the manner of application or in the way the film is immersed in water apparently exert measurable effects. But such vagaries are small in comparison with certain large differences among paints according as they do or do not contain pigments of strongly anisotropic shape. Acicular (rod-shaped) pigments evidently become oriented with their long dimensions parallel to the last direction in which the liquid paint flows before it hardens, and they retain their orientation in the hardened film even after prolonged weathering. Such orientation of acicular pigments imparts grain to the paint films that is roughly analogous to the grain in wood. It has long been observed in paint exposure tests at the Forest Products Laboratory and elsewhere that many paints, including enamels that form coatings entirely free of brush marks, crack on weathering with the predominant direction of the cracks roughly parallel to the direction in which the paint was last brushed. Since the last brushing of paint is normally parallel to the grain of the wood, it has usually been assumed that the grain of the wood controlled the direction of paint cracking by reason of the greater swelling of wood across than with the grain. The discoveries that many paints swell more than wood does, swell more across than with the last direction of flow, and therefore possess a grain of their own, confirms this Laboratory's earlier observations that it is the grain of the paint rather than the grain of the wood on which the direction of paint cracking commonly depends.

The observations of grain in free films may be briefly summarized by the following list of approximate ratios of transverse to longitudinal swelling, $\Delta B/\Delta L$, which are averages for the number of closely agreeing paints or coating materials indicated:

Kind of coating material	$\Delta B/\Delta L$
Magnesium silicate in linseed oil	2.10
Five commercial paints (all contained magnesium silicate)	1.87
Paint T(are) with all extender magnesium silicate	1.73
Seven TLZ paints with all extender magnesium silicate	1.60
Calcium carbonate (No. 1) in linseed oil	1.49
Paint T(are) with half the extender magnesium silicate and half calcium carbonate (No. 3)	1.45
Three TZ_{20} paints with half the extender magnesium silicate and half calcium carbonate (No. 2)	1.17

Kind of coating material	△B/△L
Paints L, Z, T_{420}, and LZ_{37} with no extender	1.12
Paint T(are) with all extender calcium carbonate (No. 3)	.96
Four unpigmented vehicles (linseed oils and alkyd resin)	.95

Magnesium silicate (fibrous talc) is a markedly acicular pigment; it clearly imparted grain to all the paints in which it was used, including all five of the commercial paints. Calcium carbonate No. 1 was a pigment of very high oil absorption and an appreciable degree of acicularity that imparted significant grain to paint; but calcium carbonates No. 2, low in oil absorption, and No. 3, very low in oil absorption, were granular and imparted little or no grain to paint. All of the opaque pigments used, white lead, zinc oxide, and titanium dioxide, were effectively granular enough to produce little or no grain in paint, though some of them are available in somewhat acicular grades.

Swelling Efficiency of Water: In order to study the relation between degree of swelling and the quantity of water absorbed per unit weight of oil in the films, a factor that may be called the swelling efficiency was computed for all of the films listed in tables 6 and 7. The swelling efficiency is defined as the swelling in surface

Table 10.--Loss in weight by leaching with water spray during exposure of coatings on tinplate to artificial weathering, expressed as percentage of the weight of linseed oil in the films

Coating material	Pigment volume in paint p/nv	Thinner films: Thickness	Thinner films: Loss by leaching per unit weight of oil after exposure for indicated number of kilowatt-hours: 400	800	1,200	Thicker films: Thickness	Thicker films: Loss by leaching per unit weight of oil after exposure for indicated number of kilowatt-hours: 400	800	1,200
		Mils	Percent	Percent	Percent	Mils	Percent	Percent	Percent
Group 1 - Unpigmented coating materials									
Raw linseed oil	0	6.1	15.9	22.2	28.1	12.3	10.3	14.7	17.8
Bodied linseed, Z3	0	5.8	9.9	12.7	16.3	12.7	5.7	7.6	9.1
Bodied linseed, Z6	0	6.0	7.6	10.0	12.7	13.4	5.1	6.2	7.8
Alkyd-resin	0	6.3	4.2	6.2	6.4	11.8	2.9	3.9	3.6
Group 2 - Linseed oil paints free from zinc oxide									
Magnesium silicate	0.30	4.8	13.7	21.8	28.4	7.7	9.8	14.2	18.2
Calcium carbonate	.30	3.1	18.3	31.2	39.8	6.2	9.8	15.7	20.2
L	.30	4.2	13.0	21.1	27.0	7.2	7.2	11.9	16.2
L	.36	4.2	10.2	14.4	18.8	5.0	8.8	12.5	16.2
TL40	.30	4.9	14.0	23.7	31.0	7.7	7.6	13.0	16.8
TL40	.40	4.0	17.4	31.4	39.0	5.2	12.9	23.2	29.5
T420	.09	4.2	17.4	29.8	41.2	6.3	11.5	20.6	29.0
T420	.30	5.9	12.5	18.0	21.8	8.4	7.9	10.6	13.4
Average for group 2			14.6	23.9	32.1		9.4	15.2	19.9
Group 3 - Alkyd-resin paints									
T(are)	.30	3.4	5.6	7.8	11.8	6.9	1.9	1.4	1.9
T(are)	.36	4.3	5.1	7.4	7.3	6.2	3.6	5.3	6.6
T(are)	.40	4.2	5.3	8.3	10.3	6.1	4.0	5.6	6.6
Group 4 - Linseed oil paints containing zinc oxide and of p/nv 0.30									
Z	.30	2.8	8.9	19.9	26.5	6.8	3.0	5.8	8.1
LZ37	.30	4.6	3.9	8.4	11.6	8.2	1.3	4.0	5.1
TL50Z30	.30	5.0	4.8	6.1	7.6	8.4	2.3	2.6	3.1
TL30Z25	.30	5.4	4.8	7.0	9.3	7.6	2.8	4.0	5.5
TL20Z20	.30	4.7	5.3	6.8	8.9	7.9	3.2	3.4	3.9
TL10Z10	.30	3.9	8.1	11.5	14.6	6.5	4.5	5.8	7.2
TZ20	.30	4.1	6.4	11.3	14.4	8.2	1.8	3.8	4.6
Average for group 4			6.0	10.1	13.3		2.7	4.2	5.4
Group 5 - Linseed oil paints containing zinc oxide and of p/nv 0.36 or 0.40									
$TL_{30}Z_{25}$	.36	2.9	11.0	19.8	25.6	7.1	4.2	6.4	8.9
$TL_{20}Z_{20}$	.36	4.1	2.1	11.0	13.5	6.4	4.1	5.1	6.3
$TL_{10}Z_{10}$	.36	3.6	8.9	12.8	16.0	6.7	4.1	5.8	7.2
TZ20	.36	4.0	6.1	11.3	14.0	6.2	3.2	6.6	8.1
TZ20	.40	4.0	6.0	12.0	14.9	6.1	3.6	7.5	9.3
Average for group 5			6.8	13.4	16.8		3.8	6.3	8.0
Group 6 - Commercial paints									
No. 1 - TL_7Z_{23}	.35	3.8	6.1	12.9	18.8	6.5	2.8	5.5	8.1
No. 2 - $(TL_{23}Z_{18})_{134}$	.31	4.6	5.0	8.6	12.1	7.0	1.8	2.5	5.6
No. 3 - $(TZ_{19})_{126}$	.30	3.8	8.0	8.3	12.5	6.4	2.4	3.5	5.5
No. 4 - $(TZ_{16})_{122}$	.38	4.2	4.9	9.8	14.5	7.0	2.3	4.5	7.0
No. 5 - T139(re)	.31	2.3	4.5	14.2	18.3	4.0	4.9	9.8	11.4

area, ΔQ, divided by the quantity of water absorbed per unit weight of oil in the film, A/W_o, that is, $\Delta QW_o/A$. Examination of the tabulated data then showed that the coating materials fell into certain groupings within which the swelling efficiencies were essentially the same. The groupings of coating materials were those that already appear in tables 6 and 9, except that the pure white lead paints in group 2 and commercial paint No. 5 differed from the other paints in their groups. Accordingly, table 8 lists the average swelling efficiencies for each group with the two exceptions omitted and listed separately.

All materials except commercial paint No. 5 and the alkyd-resin paints were swelled more efficiently by water when the films were freshly prepared than after weathering. Most of the reduction in efficiency from weathering was accomplished in 400 to 800 kilowatt-hours of exposure; often the efficiency after 1,200 kilowatt-hours was slightly higher than it had been after 800 kilowatt-hours. For the alkyd-resin paints, the initial swelling efficiency was lower than that of other paints except commercial paint No. 5, but the swelling efficiency for the alkyd-resin paints increased slightly after weathering. For thick films, the swelling efficiency was nearly always slightly lower than it was for thinner films, but the difference largely disappeared after weathering.

Unpigmented films were subject to higher swelling efficiency than other films when freshly prepared and, in the thicker films, throughout the weathering periods. For zinc-containing paints of pigment volume 0.30, the efficiency was slightly higher than for otherwise similar paints of pigment volume 0.36 or 0.40, but the differences in swelling efficiency were small among the zinc-containing paints of the higher pigment volume, the commercial zinc-containing paints, and the zinc-free paints other than weathered pure white lead paint.

Conspicuously unusual results were obtained with pure white lead paint and with commercial paint No. 5. For the latter, the swelling efficiency of water was slight at any stage in life. For the former, the swelling efficiency was as high as for other paints when freshly prepared, but on weathering the swelling efficiency for the thinner films of paint L quickly dropped to values nearly as low as those for commercial paint No. 5. The thicker films of white lead paint on weathering were swelled more efficiently than the thinner films but were far less swellable than other paints. "Breather-type" paints, such as commercial paint No. 5, are said to be physically porous by reason of voids in such pigments as diatomaceous silica or of interstices left unfilled by the vehicle. If so, they have a capacity for holding free water or for taking up part of the swelling of the oil internally without change in external dimensions. It is conceivable that white lead paint becomes physically porous on weathering because it is known that once it has passed well into the chalking stage the surface can no longer be restored to a glossy condition by rubbing as can be done with most other paints. MacGregor (*22*) postulated the development of such porosity during the weathering of some paints, although he did not believe that it occurs in white lead paint. At any rate, the low swelling efficiency of commercial paint No. 5 and of weathered paint L indicates clearly that such paints take up water in a manner that causes less swelling than is brought about in other paints.

Thickness of Free Films: In calculating the swelling efficiencies in table 8 it is tacitly assumed either that the thickness of free films does not change during swelling or that the thickness always changes proportionately to the area. The first assumption is certainly incorrect. The second may be true within reasonable limits but must be considered uncertain. For that reason some of the smaller differences in swelling efficiency recorded in table 8 may be misleading because they may be due chiefly to variations in the participation of thickness change in the total volumetric swelling.

It was hoped that it would be possible to measure changes in thickness as well as in length and width in these experiments, but all techniques tried so far for measuring swelling in thickness have proved too inexact for quantitative purposes. Plans for future work therefore include direct measurements of volumetric swelling of at least some of the paints and unpigmented vehicles.

All film thicknesses reported in the tables were calculated from the weight of the film, its area, and the density of the nonvolatile ingredients of the coating material while still in the liquid condition. Such computation involves an underestimation of the density of the coating material when dried and an overestimation of the film thickness because air-drying materials become measurably more dense during the process of drying (*9, 10*). Existing data, however, are inadequate for calculating the densities of the films after drying and weathering. For films of unpigmented raw linseed oil, the correction probably amounts to several tenths of a mil, but for the pigmented films, the corrections would be smaller. Actual measurements of thicknesses of the films before immersion in water confirmed the expected order of magnitude of the discrepancies.

Solubility of Free Films in Water: The quantity of soluble materials leached from the films during the determinations of absorption of water and swelling is recorded in table 9. All films tested yielded soluble materials. Thin films yielded more, in proportion to their oil content, than thick films of the same kind, as might well be expected from the greater specific surface of the thinner films. On the average, the solubility remained about as great after weathering as it was before, even though the weathering cycle involved enough spraying with water to remove much soluble material before the weathered films were subjected to immersion tests. This fact, together with the steady increase in solubility during the prolonged immersion tests reported in table 1, suggests that most, if not all, of the soluble substances reported in tables 1 and 9 were formed by reactions that took place while the films were immersed in water rather than before immersion.

The soluble ingredients leached from the unpigmented oils and from paints with insoluble, chemically inert pigments such as magnesium silicate and titanium dioxide, clearly originate in decomposition of the oxidized linseed oil in the films. The extract can be recovered from the soaking water by evaporation to dryness and is then seen to be an amorphous, glossy, amber-colored deposit that looks much like the clear material found under paint blisters of the "glossy-backed" type. When the paint contains white lead, the extract contains no more than a faint trace of lead, but the extract from paints containing zinc oxide has a substantial content of zinc, presumably as zinc salts of organic acids.

The differences in solubility among the various kinds of films recorded in table 9 were not large enough to require discussion at this time, except to point out that commercial paint No. 4 proved exceptionally high in solubility both initially and after weathering, and commercial paints Nos. 1 and 3 were unusually high when tested in the thinner films. No reason for such peculiar behavior is evident in the formulas printed on the labels of the paints.

Leaching of Coatings During Artificial Weathering: Much larger proportions of soluble substance were leached from many of the coatings by the water spray while in the weather-

ing machine than were extracted from the free films subsequently when they were immersed in water. Leaching during weathering was determined by exposing coatings applied on tared tinplate in the weathering machine side by side with the coatings on gummed paper, and by drying and weighing the coated tinplate specimens after each period of exposure. The leaching losses, expressed in percentage of the linseed oil in the coating, are reported in table 10.

Leaching losses were greater from thin than from thick coatings of the same kind of paint. Since the quantity of soluble material increased markedly during each successive interval of weathering, it is evident that the process of solubilization went on during the weathering, for all soluble material in the coatings when weathering began would surely have been extracted within the first 400 kilowatt-hours of exposure. Higher losses in the weathering machine than in 3-day immersion periods indicates that solubilization goes on faster when ultraviolet light and water act together than when water acts alone. (During one period of 400 kilowatt-hours, or 5 days, in the weathering machine the total time of subjection of the coatings to running water could not have exceeded half a day.)

Leaching losses from coatings free from zinc oxide, including white lead paint and unpigmented raw linseed oil, were notably greater than the losses from paints that contained zinc oxide. The result offers an explanation of the observation by Browne and Laughnan (6, 7) that white lead paint and titanium-lead paint waste away in coating thickness during the intervals between repaintings more rapidly than mixed-pigment paints that contain zinc oxide.

Tests of 10 Paints After Natural Weathering

Ten paints, the five commercial paints and five of those made in the laboratory, were applied in three-coat work by brushing on substrates of tinplate and of paper coated with silicone and were then exposed to natural weathering for 5½ months, from September 1952 to February 1953, facing south and sloped back at an angle of 45° from the vertical. At the end of the weathering period samples were cut, stripped from the substrates, and tested by immersion in distilled water for 72 hours. The results are reported in table 11.

The absorption, swelling, and solubility of the films exposed to natural weathering were reasonably similar to those obtained with the same paints by artificial weathering, tables 6, 7, and 9. All of the paints except pure white lead and commercial paint No. 5 were still swelling much more than southern yellow pine does even after weathering. At least for the present, it may be assumed that artificial weathering brings about changes in paint films of much the same kind as occur during natural weathering. Further results of natural weathering will be obtained when a longer period of time has elapsed. It is not possible to establish the relative rate of change by artificial and natural weathering, but the results suggest that 5½ months over a winter period are equivalent to no more than 400 kilowatt-hours in the artificial-weathering cycle used.

Table 11.--Absorption of water, swelling, and solubility of free films of five commercial and five laboratory-made paints after natural weathering for 5-1/2 months

The films were 1.5 by 2.5 inches in size, of the thickness indicated. For each paint averages are reported for four films, of which two were exposed on tinplate and two on siliconed paper. Free films were tested by immersion in distilled water at 69.5° F. for 72 hours.

Kind of paint	Pigment volume in paint p/nv	Thickness of film	Absorption of water based on weight of oil in film A/W_o	Swelling (Increase in area) ΔQ	Swelling efficiency $\Delta Q W_o/A$	Solubility, based on weight of oil in film S/W_o
		Mils	Percent	Percent	Percent	Percent
Commercial paints						
No. 1-TL_7Z_{23}	0.35	5.0	163	51	31	13.1
No. 2-$(TL_{23}Z_{18})_{134}$	.31	4.8	130	33	25	9.4
No. 3-$(TZ_{19})_{126}$	.30	4.0	128	24	18	15.2
No. 4-$(TZ_{16})_{122}$	.38	4.5	104	30	29	20.8
No. 5-T_{139}(re)	.31	2.5	99	5	4	6.7
Laboratory-made paints						
L	.30	3.3	23	2	8	6.4
LZ_{37}	.30	3.6	91	35	24	7.4
TZ_{20}	.30	3.9	126	46	36	12.7
TZ_{20}	.36	4.7	112	32	29	10.8
TZ_{20}	.40	3.6	100	26	26	11.0

Tests of Certain Paints After 16 Years of Natural Weathering

In 1936 a series of exposure tests was started at Madison in which wood panels were painted with 12 kinds of house paint and each paint was repainted at intervals, always with the same kind of paint used originally, until 1948, when painting ceased for 4 years while the results were being observed. As pointed out in other publications, (6, 7), most of the painting programs led to coatings of excessive thickness, which, if the paint contained zinc oxide, produced cross-grain cracking, curling, and scaling in relatively large pieces. Late in 1952 large chips of eight kinds of paints were collected for test by immersion in water. No paint free from zinc oxide yielded paint chips large enough for such study.

The chips collected were of various sizes and of irregular shapes. It therefore was not possible to cut them into the 1.5- by 2.5-inch or 2- by 2-inch specimens usually preferred; instead, chips were used very nearly in the sizes and shapes in which they were available. The chips selected were marked, dried, weighed and measured, immersed in distilled water for 72 hours, again weighed and measured while wet, dried over calcium chloride, and weighed and measured once more. The results are reported in table 12, in which the paints are listed in the order of decreasing content of white lead.

Although part of the paint in each of the chips was 16 years old and all of it was at least 4 years old, the chips still absorbed about as much water as

roughly similar paints did after moderate exposure to artificial weathering, as recorded in table 6. The swelling and swelling efficiency of water for the 16-year old paints were somewhat lower than the values in tables 7 and 8 for much younger paints; but when due account is taken of the great thickness of the old chips, their swelling cannot be considered much less striking than that of the younger paints after moderate weathering. Even after 16 years and in excessive thickness of film, some paints still swell more than flat-grain surfaces of southern yellow pine.

Conclusions

Free films of house paints when soaked in distilled water absorb surprisingly large amounts of water, often more than 1½ times the weight of linseed oil that the films contain. As a rule, the absorption of water causes marked swelling, which in free film finds expression in expansion of the surface area that for many paints may amount to more than 50 percent when the films are still young. Such swelling is several times as much as that of flat-grain surfaces of wood between the air-dried and the water-soaked conditions. Coatings firmly attached to wood must, of course, conform to the surface dimensions of the wood; the larger swelling of the coating must be accomplished by increase in coating thickness. Such accommodation of the dimensions of the swollen coating to the requirements of the substrate necessarily gives rise to large stresses within the coating, which, no doubt, have direct bearing on the phenomena of cracking, curling, and flaking in the normal weathering of coatings and on such abnormalities of coating behavior as blistering and peeling. Besides the absorption and swelling, water causes a leaching of water-soluble ingredients from paint films, apparently developed, at least in large part, by chemical reactions occurring while the paint films are in contact with water. Still larger losses of soluble ingredients occur during the weathering of paint coatings through the combined action of ultraviolet light and spraying with water.

For paint of any one kind, absorption and swelling are greatest when the free films have been freshly prepared. They decrease slightly with age even when the films are kept indoors in subdued light under dry conditions. Absorption and swelling usually decrease markedly on weathering either naturally or artificially, but even after 16 years of weather exposure some paints may still swell in water more than wood does.

Table 12.--Absorption of water, swelling, and solubility of paint chips from coatings exposed for 16 years on a test fence at Madison, Wis.

The paint chips were collected in 1952 from naturally loosened coatings of the "1936 Paint Maintenance Tests," which have been previously published (6, 7). The coatings on wood had been maintained by painting in 1936 and repainting at intervals until 1948, when the last coats of paint had been applied. The chips were of varying sizes and of the measured thicknesses indicated. They were tested by immersion in distilled water at 69.5° F. for 72 hours.

Kind of paint	Pigment volume in paint p/nv	Thickness of film (measured)	Absorption of water, based on weight of oil in film A/W_o	Swelling (increase in area) ΔQ	Swelling efficiency $\Delta Q W_o/A$	Solubility, based on weight of oil in film S/W_o
		Mils	Percent	Percent	Percent	Percent
LZ_{23}	0.29	17.5	36	1.7	5	2.7
LZ_{37}	.29	13.4	18	1.6	9	1.7
$(LZ_{30})_{80}$	.29	10.3	35	3.2	9	2.7
$(TZ_{28}Z_{28})_{116}$	.29	9.3	23	5.5	24	1.2
$(LZ_{15})_{33}$	.36	18.1	31	4.4	14	2.7
$(SZ_{23})_{75}$	.29	15.1	48	12.9	27	2.7
$(TZ_{23})_{107}$	.29	11.3	54	7.6	17	2.9
$(TZ_{16})_{207}$(e)	.19	10.0	26	4.2	19	1.5

Paints in which there are markedly acicular (rod-shaped) pigments swell anisotropically and, in that sense, possess grain. The grain is produced by orientation of the acicular particles during the last stroking of the paint when it is being applied. As in wood, swelling is greater across the grain of the paint than it is along the grain. Grain in paint often expresses itself in the pattern of cracking or other defects that show up later when the paint becomes embrittled with age.

Although the absorption and swelling of free paint films clearly originate in the oil vehicle, they are markedly affected by the pigments, especially if the pigments are chemically reactive. Thus zinc oxide imparts greatly increased absorption and swelling, much greater than the absorption and swelling of films of unpigmented linseed oil. Such chemically inert pigments as titanium dioxide and magnesium silicate alter the absorption and swelling of oil only moderately. On the other hand, white lead markedly reduces both absorption and swelling, especially after the paints have begun to weather. When the paint contains both zinc oxide and white lead, the augmenting effect of the zinc oxide predominates even when the proportion of zinc oxide is relatively low.

There is evidence that paints of the so-called breather type, which are claimed to be unusually resistant to blistering and peeling by reason of a porosity of their coatings, may in fact make coatings with internal void spaces capable of holding free water without a proportionate swelling or, perhaps, of accommodating much of the swelling internally rather than externally. One of the commercial paints, which dried entirely without gloss, was found to absorb a substantial amount of water without undergoing much swelling in consequence. Likewise, pure white lead paint, after it had become weathered, swelled much less than would normally result from the amount of water it absorbed. It may well be that the resistance of such paints to moisture blistering comes from the low swelling rather than from the alleged ability to breathe by letting moisture readily pass out from the substrate through the coating.

Further studies of the absorption of water, swelling, and solubility of free films of house paints offer promise of explaining many of the phenomena of paint behavior that have so far been subject to great diversity of opinion, and of furnishing a tool for the search for better paints. But until such further studies have been made, and particularly until a connection between swelling of free films and blistering

of paint coatings has been established by direct experiment, it would be unwise to evaluate paints for practical use on the basis of the absorption of water and swelling of their free films.

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Discussion

Ross Martin (Sears Roebuck): What is the effect of flow under gravity while making samples on the grain of the free films?

Dr. Browne: The coatings were spread on surfaces in a horizontal position and were kept in that position while the coatings dried. Any effect of gravity would therefore be in the direction of a stratification from top to bottom of the coating. Any effect of

that kind is probably small in coatings of high pigmentation and 3 to 6 mils in thickness, especially so since nearly all of the pigmented coating materials had the consistency of house paints and therefore were non-Newtonian in flow properties and possessed an appreciable yield value. In any event the action of gravity would be without regard for length or breadth of the free films and could not have produced the grain observed in paints made with acicular pigments. (It is expected that subsequent work will permit a more direct evaluation of any possible effect of gravity.)

Paul Blackmore (Interchemical Corp.): Were any experiments made to see whether absorption and swelling of paint films are related to their permeability to water vapor?

Dr. Browne: No measurements of permeability to water or to water vapor have been made with free paint films at the Forest Products Laboratory, though a number of other workers have recorded such measurements in the literature. For examples see Edwards and Wray, *Ind. Eng. Chem.* 28: 549(1936), Wray and Van Vorst, *ibid.* 25: 842 (1933) and Edwards, *ibid.* 25: 846 (1933). The method used at the Forest Products Laboratory involves measurements of coatings applied on all surfaces of pieces of wood, Browne, *Ind. Eng. Chem.* 25: 835(1933) and 28: 798(1936). Coatings on wood permit the passage of moisture at about the same rate when in contact with liquid water or with moisture-saturated air. No relation has yet been found between the absorption of water and swelling of films of paints of different compositions and the permeability of the films either as free films or as coatings on wood. Within the limits of composition characteristic of house paints, a paint may be either relatively high or relatively low in permeability and yet may absorb much water and swell greatly. Much speculation on this subject has been unsupported by evidence.

Mr. Blackmore: May not absorption and swelling of paint films be a useful mechanism for facilitating the escape of moisture that enters the substrate through the unpainted back of boards of siding, for example, and must be able to pass out again through the painted face? If moisture cannot so escape it may swell the wood and cause checking and cracking of the coating.

Dr. Browne: At the present stage of our studies we are trying to learn how water affects coatings of house paints before and after aging. Interpretation of the facts in terms of the practical problems of painting houses may well wait until we get the facts together more completely. Tentatively, however, it may be pointed out that checking, which is the development of fissures that begin superficially and usually take a long time to penetrate all the way through a coating, does not offer escape passages for moisture. Moreover, checking patterns are characteristic of the kind of paint, the combination of paints, the thickness of coating, and sometimes of the method of applying the paint but is independent of the nature of the substrate. A given paint system checks according to its characteristic pattern whether it is applied on swellable wood, on permeable but non-swellable stucco, or on impermeable and non-swellable metal.

Cracking, which is the development of fissures that pass entirely through a coating from their outset, does afford escape passages for moisture, though they are not necessarily very effective. Like checking, cracking occurs on non-swellable as well as on swellable substrates. Moreover, those of us who have been observing test fences and houses carefully for many years know that freshly formed cracks do not appear during the spring thaws or during prolonged wet weather when wood and coating are at their maxima of moisture content. New cracks appear during or near the end of dry spells when wood and coating are at their driest. Such observations conflict with the theory that cracking occurs when wood by swelling puts the coating of paint in severe tension. But they are in harmony with the present findings that free films of paints known to be prone to conspicuous cracking swell and shrink more than wood does whereas paints known to be highly resistant to cracking swell and shrink no more than wood does. If inequality in swelling and shrinking between wood and paint coating is responsible for deterioration of paint our problem is to hold the swelling of paint down to no more than that of wood, for it would certainly be objectionable to increase the swelling of wood.

G. F. Sward (National Paint, Varnish and Lacquer Association): Are paint blisters caused by swelling of paint coatings?

Dr. Browne: Henry Green advanced the theory that so-called moisture blistering of paint on houses is caused by absorption of water and swelling of the paint in his testimony in the litigation of City Housing Corp. vs. New Jersey Zinc Co. before the Supreme Court of New Jersey in 1935. It should be remembered, however, that paint blistering may arise from a number of different causes not all of which involve moisture. Sudden heating of a coating to a fairly high temperature, whether the coating is on wood or metal, is one way to make it blister; use is made of it in removing old paint by blow torch. Good painters "follow the sun around a house" to avoid the temperature blistering that may occur in a freshly applied coat of paint that is skin-dry but is still soft underneath when it is heated moderately by strong sunshine. In that case the pressure to raise blisters may come from expansion of air in the wood underneath or from volatilization of paint solvents still present in the coating. Then there is the rather frequent development on houses that have been painted more than once of "glossy-backed" blistering, in which an unpigmented, glossy, and often rumpled layer of varnish-like material is seen on the back of the loosened paint and on the surface underneath. At times the glossy material is found as a soft, tacky, very viscous liquid and at other times it is firm and hard. Such blistering comes about from a re-softening of an old layer of paint long barred from contact with air and light by more recently applied paint. There may be an evolution of gas in the softened layer to force up the blister, there may be a temperature rise while the buried layer is soft as in the temperature blistering of freshly applied and skin dry paint, or the most recent layers of paint may swell and come loose from the softened layer when water is absorbed or when paint liquids are taken up as a brand new coat of paint is being applied.

The kind of blistering produced by typical cold-weather condensation in houses arises from a fluid (gas or liquid) pressure exerted against the back of the paint coating at a time when the coating has been softened, plasticized, and its adhesion weakened by the absorption of water. Swelling of the paint film may also be involved but if so the paint film must swell more than the wood does for the blister would be drawn down against the wood again if the wood swelled more than the paint did. Moisture blistering of this kind has been described in detail since 1927 in Forest Products Laboratory Report No. R6, which has had wide distribution.

To come back directly to Mr. Sward's question, however, we know that paint coatings can easily be made to blister by swelling them with the solvent mixtures of which paint removers are made. The blisters do not always take the well rounded shape commonly associated with other forms of blistering but rounded blisters can usually be brought about by moderating the speed and severity of the swelling action, as by letting only

(Continued on page 226)

Sanding Wood for Finishing

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There are several inter-related operations involved in preparing wood for finishing. These include kiln drying, storage, control of atmospheric conditions in plant during manufacturing, machining and sanding. Although this paper is primarily concerned with sanding, it is emphasized that quality and cost of sanding is always directly and definitely affected by the quality of preceding operations.

SANDING IN MOST WOODWORKING plants is classified into three different categories: sanding before finishing, sanding intermediate finishing coats and wet sanding the finish coat. We are limiting this discussion to sanding before finishing. Before discussing sanding, perhaps we should first discuss coated abrasives, with which the sanding is done.

Coated Abrasives

Coated abrasives (often called sandpaper) consist of abrasive minerals, or grains, firmly anchored by adhesives to backings of paper, cloth or fibre. It is a "far cry" indeed from the Mid-Eighteenth Century product which was made of ground glass, with its very limited use, to the present day abrasives, some of which are almost as hard as diamonds, coated on paper and cloth backings with specially developed adhesives and capable of being run at terrific speeds, and used for grinding and polishing even the hardest metals. It is not generally realized that coated abrasives are used in some manner in practically all types of manufacturing—wood, metals, glass, plastics, leather, felt hats and for removing stains from eggs and skins from peanuts.

Grains: There are 3 abrasive minerals commonly used in making abrasive grains for wood sanding. The oldest and still very commonly used, is Garnet, which is a natural mineral. Garnet is generally heat treated to make it harder and tougher, and to increase its cutting efficiency.

Then, we have Aluminum Oxide and Silicon Carbide, both of which are artificial minerals produced by putting certain minerals in electric furnaces and heating them to very high temperatures. Both of these artificial minerals are considerably harder than Garnet and will generally outlast Garnet on most wood sanding operations. All of these abrasive minerals are originally in chunks of various sizes and they must be crushed into the various abrasive grain sizes. These abrasive grains are then separated into the desired sizes by means of very accurately hand-woven silk screens. These screen mesh openings are used to designate the size of the abrasive grain; thus, a 100 grit grain will go through a screen mesh with 100 openings per lineal inch. In the early beginnings of the manufacture of coated abrasives, an arbitrary gradation designation was used, such as 1/0, 2/0, etc. When the screen mesh sizes were adopted, in order to avoid confusion especially in woodworking plants who were accustomed to the old arbitrary grade markings, it was decided to duplicate these markings; hence, we have 0–80, 2/0–100, etc. It is hoped that this duplication of grade designation can be eliminated in the not-too-far-distant future.

Backings: Cloth backing and paper backing are most commonly used in wood sanding, and fibre backing is gaining wide acceptance for multiple drum sanding. Also, a combination backing, which is a thin layer of paper and a thin layer of cloth cemented together, is used on certain strenuous drum sanding operations. Paper backing is available in several different weights and flexes beginning with the light, flexible "A" weight commonly used in the Finishing departments; "C" and "D" weights commonly used for hand sanding in the cabinet department; and the heavier 5-ply "E" weight commonly used for belts and drum sanders. There are two weights of cloth backings used—the heavier "X" weight which is commonly used for edge belt and other sanding operations where flexibility is not required; and "J" weight or jeans which is a lighter weight backing and which is available in various degrees of flexing to meet the requirements of various types of molding sanding and similar operations.

Bonds: The bonds or adhesives commonly used in making coated abrasives are high grade animal glues and resins of several different types. Until a few years ago, only glues and waterproof resins were commonly used in making coated abrasives. These waterproof resins are essentially expensive and difficult to handle in the manufacturing processes. Recently, other types of resins, which are not as waterproof but which are more practical to handle in the manufacturing of coated abrasives, and which are less affected by heat and moisture than is glue, have been found and many of the new coated abrasives made with this type of resin bonding have given outstanding performances in wood sanding. Another new abrasive is made with a combination of animal glue and resin bonding and this, too, has been outstanding.

Coatings: Most of us are familiar with Closekote which is generally used where flexibility is not required, and Openkote which is generally used for flexible moulding cloth and for finishing papers and for some Cabinet papers. Many of us cannot so readily distinguish between products which have been coated by the old-fashioned

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method where the grain is sifted down on to the adhesive, and the electro-coated process where the adhesive is applied to the underneath side of the backing and the abrasive grain is applied by electrostatic process, until we have compared these two methods of coating and discovered the extra sharpness of the electro-coated product and have compared the productive capacity of these two methods of coating and discovered that the electro-coated product will generally considerably out-perform the gravity-coated product.

Sanding Before Finishing

Each sanding operation in a plant should be considered in its relation to all other preceding and succeeding sanding operations, and it should also be kept in mind that the kiln drying and other machining operations have a direct bearing on sanding. There is very little real economy effected by using too coarse grits on the multiple drum sander if this results in additional belt polishing, nor is there any economy in a poor sanding job in the sanding department or cabinet department which results in excessive sanding in the finishing department. There are so many varying conditions in different plants and such wide differences of opinion among sanding operators, supervisors and executives as to what is the best sanding procedure that it would be almost impossible to outline a definite procedure which would meet with general approval. Therefore, our remarks as to procedure and grit sizes are not to be taken as definite recommendations, but rather as a general overall procedure which is subject to revision to suit specific cases.

There is considerable difference of opinion as to what really constitutes a well sanded surface. For purposes of this discussion, we will consider that a well sanded surface is a surface where all machine marks and other irregularities have been removed and the wood fibres cut down and the abrasive scratch marks eliminated or reduced to the point where the wood surface may be satisfactorily finished. To obtain this desired result, we suggest the following general procedure.

Multiple Drum Sander

In most plants, the first sanding operation is on the multiple drum sander. There are several different types of multiple drum sanders; i.e., endless bed, roll feed, straight jaw, and spiral drum. The endless bed type is generally preferred in furniture plants, and the roll feed is generally found in plywood plants. Straight jaw and spiral drum is a most controversial subject, preference depending on previous experience. Some plants use a drum sander as a planer and, in addition to sanding very roughly machined stock, they flush dust panels and on the same machine try to do a good job of sanding face veneers. The results are seldom satisfactory. Other plants do a very excellent preceding machining job which enables them to use fine abrasive grits on their multiple drum sander.

Some plants have one machine with coarse grits for miscellaneous jobs, and another machine with finer grits for veneered panels and accurately machined solid stock. Also, many large plywood manufacturers and furniture manufacturers have discontinued sanding large veneered panels on the drum sander because of the frequency of sanding through veneers and, instead, these people rough sand these large veneered panels with a double belt generally using ½ grit for rough sanding and 2/0 for intermediate.

Where there is only one multiple drum sander in a plant and where this machine is used for general work including the sanding of solid stock, glued-up frames and veneer panels, a common abrasive grit selection is No. 40 (1½), No. 60 (½), No. 100 (2/0) or No. 50 (1), No. 80 (0), No. 120 (3/0). When sanding veneered panels, the first drum is frequently raised clear, thus using only the last two drums. In plants which do excellent machining, grit sizes used are frequently No. 80 (0), No. 100 (2/0), No. 120 (3/0), and sometimes may go as fine as No. 150 (4/0) on the last drum. This setup is also very satisfactory for sanding veneered panels.

Closekote Garnet Paper and Closekote Adalox Paper in all the above grit sizes are commonly used on multiple drum sanders and, recently, fibre-backed material in grits 120 and coarser has met wide acceptance, as has the new Resinized Aluminum Oxide and Silicon Carbide papers. Some manufacturers of low priced furniture finish directly from the multiple drum sander, but in plants manufacturing medium and high grade furniture practically all visible surfaces are belt polished after drum sanding.

Polishing Belts

There are 3 general types of polishing belt machines in common use. The oldest, and the one which is still used for general purpose sanding and polishing, is the hand block sander, and then we have the lever stroke machine, and the automatic stroke machine. Both the lever stroke and the automatic stroke are available in either single belts or double belts, and on the automatic stroke the hydraulic system has just about replaced the old gear and cable mechanism on the new machines. There is a wide difference of opinion as to the relative merits of these 3 different types of machines. In general, the automatic stroke is preferred for polishing large straight panels, whereas the other two types are generally preferred where there is considerable spotting, or for polishing round tops or panels with irregular edges, etc. The double belt machines are considered very practical where two belting operations are desirable unless glue sizing is practiced, in which case the double belt is not practical because in order for glue sizing to be effective it should be done prior to the last belting. Abrasive grit sizes used on polishing belts vary considerably according to conditions. Where one belting operation only is employed, it is seldom practical to go more than one grit size finer than the grit on the last drum of the multiple drum sander. In other words, if 2/0 is the last grit on the multiple drum sander, a 3/0 belt would generally be used. If too big a jump is made between the last grit on the drum sander and the grit used on the abrasive belt, the wood fibres are generally not properly cut down and a high gloss surface is produced which is sometimes mistaken for a good sanded surface, but generally an excessive amount of sanding results in the finishing department. Where two polishing belts are used, it would be good practice to use the same grit or one grit finer than the last drum on the first belt and jump two grits to the final belt. To summarize, the grit sizes commonly used on polishing belts vary from 0 through 7/0.

For the past several years, the trend has been to increase the speeds of polishing belts and this has proven very practical in the coarser grits and on many different types of wood, but in grit 5/0 and finer, and especially on wood such as mahogany, considerable burning has been experienced at these higher speeds and experience so far seems to indicate that 5000 SFPM is about the maximum speed for these fine grits on mahogany and similar woods.

Edge Belt Sanders

A wide variety of jobs are sanded on edge belt machines and grit sizes used include ½, 0, 2/0 and 3/0. "X" weight Garnet Cloth is generally used although there is some preference for "X" weight Aluminum Oxide Cloth and many plants have found it practical to use paper belts for straight edge sanding.

Sanding Mouldings

The efficient sanding of mouldings requires a considerable amount of ingenuity. Many different methods are employed, depending upon the shape and detail of the moulding, the volume, and frequently upon the ability of the available mould sanding operators. The most efficient and most commonly used method is the moulding belt. However, many moulding shapes cannot be readily sanded on a belt, and must be sanded on one of the several spindle machines with flexible cloth abrasive fastened over a felt or rubber wheel shaped to fit the moulding. And some mouldings are so delicate or complicated, or the volume is so small, that it is more practical to sand them by hand. There are two types of moulding belt machines —one uses the hand block method and the other the fixed block method. The fixed block method is commonly used for simple mouldings and is more highly productive, whereas the hand block method is commonly used for more complicated mouldings or for sanding odd shapes. Openkote Jeans Cloth in either Garnet or Aluminum Oxide and in grits ½, 0, 2/0 and sometimes 3/0 are commonly used. Moulding cloth is available in several different degrees of flexibility, such as unflexed, singleflex, doubleflex and tripleflex. The shape of the moulding and the preference of the operator generally determines which flexibility is used. Moulding belts are usually run at a comparatively slow speed of between 2500 SFPM and 3000 SFPM, since a high speed will frequently cause burning and will also make it more difficult to control the belt.

Turning Sander

Most turnings are sanded on the automatic brush type machine similar to the Nash turning sander, and scored Garnet or Aluminum Oxide Paper in grits ½ through 5/0 inclusive are commonly used, depending upon condition of turning and finish desired.

Miscellaneous Machine Sanders

There is a wide variety of other machine sanding operations, such as variety belts, strapping belts, pneumatic drums, spindle sanders, etc., which are commonly used in most furniture plants, but time does not permit the discussion of these machines in detail. However, if someone would like a discussion of any one of these special type machines, we would be happy to do so.

Sanding—Cabinet or Assembly Department

Most progressive plants make every effort to deliver the parts to the assembly department completely sanded so that the amount of sanding in the assembly department can be reduced to an absolute minimum. However, in spite of all efforts along this line, a certain amount of hand sanding continues to exist in the cabinet or assembly department. Some of this is on odd-shaped parts which are inaccessible or impractical to machine sand, and on certain types of furniture where joints are flushed after assembly, which usually necessitates sanding after flushing. Then, there is a certain amount of sanding necessary to remove mars which result from handling. Also, many concerns are finding it very desirable to sand all prominent face surfaces with one of the several "jitterbug" types of machines just before the furniture goes into the finishing department. 5/0, 6/0 or 7/0 abrasive paper is generally used on these little machines, and for hand sanding, grits 0 through 5/0 in Cabinet Paper or Finishing Paper are commonly used. Close supervision should be exercised to assure that too coarse a grit size is not used.

Discussion

G. A. Seidel (Splicedwood Corp.): In some plywoods with high moisture content, when sanded with fine grits, the surface later gets fuzzy.

Mr. Gordon: Certain woods will do this. May be caused by lack of glue size. Or too big a jump in abrasive grit size results in burnishing, or failure to sand off fuzz.

Mr. Seidel: What can be done about it?

Mr. Gordon: Excessive moisture is hard to beat. May be necessary to re-sand after storing for some time.

Jack E. D. Batson (Kittinger Company): Is hot or cold pressed plywood better for sanding?

Mr. Gordon: Depends on quality of whole panel job. If a good panel with good surface, there's not much difference.

Ellis Bolton (Stevens): Please explain use of flexed and non-flexed belts?

Mr. Gordon: Single flexed or unflexed belts used for sanding intricate moulded shapes, but require experienced operator. Will hold shape better than flexed belt. Flexible belts used for sanding simple shaped mouldings or where operators are inexperienced in creasing and shaping.

Wayne Hutchins (Baker Furniture Company): We have used worn belts for developing a polish on such woods as mahogany, cherry and walnut. Any comment?

Mr. Gordon: An abrasive is made to cut. Old belts don't cut well. They are sometimes used for final sanding on close grained woods such as walnut.

Ralph Gasselman (Paine Lumber Company): What is fastest finishing speed with 00 or 000 belts.

Mr. Gordon: 7,500 FPM.

Factors Affecting the Integrity of a Furniture Finish

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Physical factors that result in finish of high integrity are discussed. Emphasis is laid on fact that integrity of finish is intimately related to details of finishing process, since finishing products are formulated to meet specific production requirements. In addition, the formula should reflect a frank and open statement by the customer as to what degree of quality he wants in his finish.

INTEGRITY, ACCORDING to Noah Webster, is "Moral soundness, honesty, freedom from corrupting influence or practise, strictness in the fulfilling of contracts". One may very well ask, "How, then, can a word like 'Integrity' be applied to an inanimate substance such as a furniture finish?" The answer is, of course, that an inanimate object can, in its performance, only reflect the integrity or honesty of its creator. The opportunities for being honest, or otherwise, are great, and depend largely on the pressures, economic and otherwise, brought to bear upon the manufacturer, and on his ability and will to resist them.

It is our purpose, in this discussion, to relate what, in our opinion, constitutes honesty in the manufacture and sale of furniture finishes.

The moral side of the story is certainly an important one and I would like to say a little more about that later on, but first let us look at the physical factors which result in a finish of high integrity.

The first place a finish can go wrong is during application. Any number of things may happen.

Beginning with the filler, one may run in to difficult wiping. This is usually the result of an effort on the part of the formulator to reduce the processing cycle and permit the topcoats to be applied in less time. Difficult wiping is seldom encountered in the old oil type fillers, but, by the same token they require overnight or longer to achieve a state of dryness that will permit the topcoats to be applied without undue puffing of the pores. As one re-inforces the drying characteristics in an effort to speed up the cycle the very property you are trying to improve works against you from an application standpoint. Thus, there must be an agreement between vendor and buyer as to how much of a compromise between faster drying and difficult wiping is acceptable. Fillers are presently available which will dry to recoat in a half hour, but they must be applied and wiped on a very strict schedule. Minutes count. If the wiping time is ten minutes, fifteen minutes starts to give trouble and in twenty minutes it is too late.

These fast-drying, synthetic fillers are designed for production line work, and where schedules can be successfully maintained, they form the base for a high integrity finishing system. They are less subject to attack by the solvents in the topcoats and if a careful filling job is done in the first place there is less likelihood of puffing and after shrinkage.

Filling properties are, of course, a function of filler solids, particularly pigment solids, and here is an opportunity for the filler integrity to suffer if the manufacturer is faced with an unsatisfactory economic picture. Cutting the solids is the fastest way toward cutting costs. Thus, a lower price per pound may not necessarily accrue to the advantage of the buyer.

Shrinkage

Another common filler defect is shrinkage. This may result from a filler that is too low in solids, for the reason previously described, or one that has been thinned too far during application. In some instances the feeling exists that the filling operation is a necessary evil on which should be spent as little time and money as possible. This is far from the truth. The filling operation is the foundation of your house and a poor filling job can cause trouble right on through the entire finishing operation and for years thereafter.

Shrinkage will take place if the filler solids are too high in liquid binder and too low in pigment. The liquid binders will shrink on drying whereas pigments may pack a little in the pores, but will not shrink. Thus, proper formulation is a very important factor as to whether or not shrinkage will take place.

Shrinkage may also be a function of the moisture content of the wood and subsequent humidity changes during the drying period. If humidity conditions are such that the actual physical volume of the pore increases due to swelling after the filler has been applied, there will not be enough filler present to fill the hole, and apparent shrinkage will be the result.

If shrinkage is discovered before the sealers or finishing coats are applied, it can be corrected by repeating the filling operation. However, this merely corrects the effect, not the cause. For future operations, the true cause should be found and eliminated. Unfortunately, in present day, high-speed finishing operations, filler shrinkage is seldom detected until after the finishing coats have been applied. The remedy at that stage is to allow the finish to become thoroughly dry by aging, or to force dry in a low heat oven, followed by careful sanding of the surface until all of the depressions caused by the shrinkage have been eliminated, and then apply a final finishing coat, rubbing and polishing after drying is completed.

Puffing

Puffing is a phenomenon that usually occurs when topcoats are applied over a filler that is too high in vehicle solids or one that is not thoroughly dry. It happens particularly in the case

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of oil base fillers normally requiring overnight or longer before recoating with the finishing coats.

It is known that a drying oil forms cell-like structures known as "micelles" during the drying process. These micelles have walls of solid or gelled oil and have a tendency to imbibe liquids with which they are brought in contact. Very much like a sponge in structure, they behave very much like a sponge in practice, swelling appreciably as the liquids are imbibed. The liquids in this case are the solvents and the fluid vehicle portions of the finishing materials which are applied over the fillers. Being restricted from lateral expansion by the confines of the pore walls, they must expand up and out of the pore. When this happens, it appears as if the grain pattern of the wood had literally swelled. If allowed to stand long enough, the swelling will be reduced as solvent is lost from the pore, but this may take days, and sufficient storage space is seldom available to permit this to take place. What usually happens is that they go after the difficulty with sandpaper, sanding off the ridges and applying another finishing coat as before. However, the swollen pore will continue to lose solvent on aging, and since it has now been sanded flush with the surface, it will ultimately shrink below it, and the original puffing defect will give way to one of shrinkage.

If a filler that has been properly dried according to the manufacturer's recommendations still shows puffing upon recoating, the defect should be called to his attention. It may be that the filler has lost some of its drying ability on aging due to adsorption of drier.

Super strong solvents in the sealer or finishing coat may also cause puffing. In any event, the cause rather than the effect should be found and eliminated because, as pointed out above, eliminating the effect usually results in a shrinkage problem.

Graying of Pores

This is one of the most common and most annoying of filler difficulties. It may be the result of a number of things.

Fillers are composed largely of silicate pigments colored with only enough strong toners to produce the desired shade. If the pigment combination that goes into a given filler is stirred together dry, it will be quite gray in color. The moment this dry pigment mixture is wetted with water, solvent, oil or any other medium that will change the refractive index of the mass, it immediately assumes the predominating color of the prime pigments used in the composition. If the liquid medium be water or solvent, and if it is allowed to evaporate, the color will return to its original gray state. This is due to the fact that the silicate pigments have a high degree of opacity and tinting strength in the dry state, but when they are wet, they are weak and transparent. The umbers, siennas and vandykes, on the other hand, develop a strong color when they are wet so that the whiting effect of the extenders is completely masked. Since fillers are by nature extremely high in pigment and low in binder, it sometimes happens that there is little or no more oil present than just enough to satisfy the oil absorption requirements of the pigment. If any other source makes a demand on this oil, such as capillary attraction by the cells of the wood, the amount of oil left may be less than that required to wet the pigment, and the silicate pigments regain, to a degree, their dry hiding value, and the effect is the same as if a white pigment had been added to the pigment mix. If the wood appears to be exerting a considerable suction effect on the filler, it may be reduced or eliminated by applying a wash coat of lacquer sealer, thinned way down in solids. This tends to seal off the capillaries and stop the suction. The filler may then be applied over the wash coat without subsequently turning gray.

Actual photomicrographs have been made which show that there is sometimes a tendency for actual pigment migration in the pore. If there is any vehicle motion due to suction, it may carry with it some of the finer pigment particles, and since the motion is into the wood, and if these fines happen to be the color forming bodies, they migrate to the bottom of the pore, leaving the white silicate pigments at the top. If this happens, graying will be the inevitable result.

It is also felt that graying may sometimes be the result of under dried filler, and that the grayness is caused by an oil bloom. Graying of pores has been found to be much more prevalent in mahogany than in walnut or other open grained woods, a fact which has not been suitably explained.

In application of sealers and topcoats a whole new set of difficulties may arise.

Pinholing

Pinholing is one of the most common defects, and it can be caused by a number of conditions. It may be caused by the presence of water or oil in the air lines. Both of them are incompatible with the finishing material and will form little globules in the film which may break through of their own accord, or which may remain as a submerged bubble until released during subsequent sanding operations. Very often pinholes are invisible until sanding has been performed on the surface, during which operation the products of attrition are deposited in the voids of the pinhole, showing up as white specks.

Pinholing may also be caused by too much air pressure, by improper solvent balance, (usually an excess of a highly volatile solvent such as ethyl acetate), spraying a surface that is too warm, trapping of air or moisture in the pores (a condition which is usually the result of a poor filling job) The effect of pinholing may also be produced by the accumulation of dirt on the wet surface which is subsequently removed during the sanding operation leaving holes which fill up with the products of attrition.

Whatever the cause, pinhole defects can be repaired only by repeated sanding and refinishing until they have been mechanically eliminated. As always, it is important to find and eliminate the cause rather than the effect.

Blushing

Blushing is a very familiar phenomenon, and one which is fairly easily corrected. Blushing is usually associated with high humidity conditions in the finishing room. It is a well known fact that when any sort of a solvent evaporates from a surface, that surface is cooled because some of its heat goes to supply the latent heat of evaporation of the solvent. If the relative humidity in the room is close to the dew point, that few degrees of cooling may be enough to cause water to precipitate on the surface of the film. Water, being a precipitant for nitrocellulose and most other film formers, causes the film solids to fall out of solution in a finely divided, colloidal form at the point of contact with the moisture. If the solvent is slow enough and rich enough, this precipitate may redissolve of its own accord before the film becomes finally dry, and if it does, no harm is done. If the film dries before the blush disappears, it will be permanent. However, the defect can usually be corrected by adding five or ten percent of a slow, rich thinner to the lacquer. This reduces the evaporation rate and therefore the rate of cooling. It also helps to keep the film open long enough so that any blush which appears may be redissolved. In the event the blush does not redissolve, it may be eliminated by spraying the affected surface with the slow solvent.

Blushing may also be caused by an improper solvent balance in the lac-

quer. Most lacquer thinners are composed of mixtures of esters and/or ketones with aromatic and aliphatic hydrocarbons such as toluol, xylol, and petroleum diluents. The latter are not solvents for nitrocellulose, but are tolerated by it in quantities up to 60 or 70 percent of the solvent mixture. Thus the hydrocarbons are used to reduce the solvent strength of the thinner (so that it will not swell fillers, pop under-coats and be otherwise generally obnoxious), as well as to make the thinner economically more attractive. However, if a thinner formulator gets too close to the economic border line, he may find himself in a position where somewhere during the evaporation rate the thinner composition develops an excess of hydrocarbon, in which case the hydrocarbon insoluble portions of the film-forming solids pop out of solution, causing a blush. Correction of the defect is the same as before—namely, spraying with a strong, slow solvent. However, it is much better to put the strong, slow solvent in the thinner in the first place and prevent the blush from occurring. Here is another instance where the integrity of the finish may be affected by the integrity of the formulator and his ability to resist economic pressures.

Runs and Sags

Runs and sags are mechanical defects and are caused by applying too much material in one place causing it to flow of its own sheer weight. Runs and sags are most prevalent on a vertical surface but are also in evidence on flat surfaces where the material runs toward one edge and tends to pile up on that edge. This condition is known as a "fatty edge". Runs and sags may be overcome by:

1. Building up the viscosity (using less thinner)
2. Using a more volatile thinner which allows a sharp rise in viscosity between the gun and the work.
3. Cutting down the pressure on the tank which, in effect, means putting on less material, and
4. Getting better atomization, either by stepping up the atomization pressure or by using a better tip on the spray gun.

Creeping or Crawling

Occasionally a finishing material will tend to pucker or creep on drying. This is usually a phenomenon of poor wetting and is observed frequently in certain types of vehicles, such as spirit soluble phenolics. Where the surface tension of the vehicle is high, it becomes extremely sensitive to small amounts of dirt or grease on the surface being sprayed. Sometimes a surface tension reducer can be found that will eliminate this tendency. Usually, however, it is simpler to eliminate the source of grease or dirt.

Crawling may also be caused by the presence of solid, incompatible substances in the finishing material. In the case of varnishes, invisible gel particles formed during the cooking of the varnish and not removed by ordinary filtration processes may cause crawling. Waxes and other agents added to films in small amounts to create marproofness may cause crawling if used in excess.

Lifting

Lifting is a phenomenon seldom encountered in lacquers, but frequently in varnishes. Everyone has seen the effect of paint remover on a varnish film. The same thing frequently happens when a second coat of material is applied over a first coat that has not thoroughly dried. It occurs infrequently in lacquers because most wood lacquers contain little or no oxidizing type resins. Lifting is probably associated with micelle formation during oxidation, and the resultant imbibing and swelling of the film when additional liquid is added. In most oxidizing type films there seems to be a critical period during the drying time when lifting will occur. Before oxidation gets well started (before the micelles are formed), the film may be recoated without danger. Likewise after oxidation is well along (the micelles have become well filled with solid vehicle), recoating may also be performed without damage. During this critical period of a few hours, however, lifting is almost sure to occur, especially where the solvents used in the subsequent coats are strong.

Lifting may also be caused by the presence of dirt, grease or wax on the surface being coated. If any of these materials are present and did not show up as creeping or crawling during the initial application, they may show up as lifting during the second coat application due to the fact that the first coat has not developed adhesion at the affected points.

In lacquers, lifting may be eliminated by avoiding the use of oxidizing type resins. This may not be desirable for other reasons, such as a sacrifice in film toughness or adhesion. Lifting may be reduced or eliminated by using weaker solvents in subsequent coats, by allowing sufficient drying time or by force drying the undercoats, or by recoating immediately before drying has had a chance to take place.

Poor Sanding

Sealers are usually sanded to overcome any surface irregularities that remain in the wood, and to knock down any wood fibres that may have been raised during the initial coating operation. In order to facilitate sanding, small amounts of metallic soaps, such as zinc stearates, are added. Unfortunately, these pigments contribute to undue softness and poor film strength as well as poor adhesion between sealer and topcoat. Thus, there is the tendency of the finish manufacturer to use the minimum amount of stearate that will satisfy the sanding requirements of the customer. Sometimes he may lean over a little backwards, and then the film will clog up the sandpaper, causing it to be replaced more frequently. Since sandpaper represents one of the substantial items of finishing cost, this usually results in a bitter complaint. However, the medicine (more zinc stearate) may frequently cause more of a headache than the disease for reasons described above.

Poor sanding may also be caused by an under-dried film which may in turn result from:

1. Too much film thickness,
2. Too slow a solvent,
3. Poor ventilation in the drying room,
4. An excess of plasticizer in the formula,
5. Presence of wax on the surface (from paint remover, perhaps),
6. Absorption of oil or plasticizer from an under-dried filler,
7. Too low a temperature to permit normal release of solvent,
8. Use of resins having poor solvent release (usually a function of low melting point),
9. Improper solvent balance causing rapid drying of the film surface (case-hardening) but trapping considerable solvent underneath, which acts as a temporary plasticizer as long as it is present.

Shelving or Laminating

This phenomenon is the result of failure of the topcoats to adhere to those previously applied so that when the film is finally dried, one can separate one coat from the other by scratching with the fingernail or a knife blade. If shelving does not show up at once, it will usually become manifest during the rubbing and polishing or touch-up operations because if the film is sanded or rubbed through, the topcoat will begin to tear away from the under coat and will continue to do so as long as sanding or rubbing is attempted. Shelving may be caused by:

1. Too much metallic soap in the sealer,
2. First coat dried too long before application of the second,
3. Too weak a solvent mixture in the topcoat,
4. Low natural adhesion in the topcoat,
5. Brittleness in the topcoat,
6. Grease or dirt between coats due to excessive and careless handling.

Shelving can seldom be repaired except by complete stripping and refinishing of the work. It may be worth while to try spraying with strong solvent or putting in an oven to see if the two coats can be fused together, but more often than not such attempts will be doomed to failure.

Excessive Orange Peel

Orange peel is a phenomenon well described by the name. It is a pebbly surface very much like that of an orange, and is caused by failure of the film to flow out smoothly after being deposited.

The need for flow is occasioned by the fact that the spray gun deposits the film in the form of droplets which must flow to continuity before drying takes place. Thus orange peel may be a function of the degree of atomization of the finishing material leaving the gun. This in turn may be a function of the air pressure, the fluid pressure, the type of atomizing tip, the viscosity of the material, the temperature, or a host of other variables.

Orange peel may or may not be serious depending upon the ability (or lack of it) of the material to flow after it hits the work, and the attitude of the customer toward orange peel. The ability to flow will be a function of the wetness of the film, the viscosity of the material, the choice of solvents, the temperature in the drying room and how much the coat in question penetrates the surface on which it is applied, or bites into the under coats over which it is applied. A material which may flow beautifully when applied as a first coat on bare wood or metal may not flow at all when applied as a second coat over itself. Conditions of environment are all important and must be controlled accordingly.

Orange peel may be overcome by spraying at reduced viscosity, by using slower solvents, higher atomizing pressures, better atomizing tips, spraying at higher fluid temperatures (which amounts to lowering the viscosity), spraying in a cooler room (which prevents the film from setting up before it can flow out), avoiding sudden drafts (also tending to set up the films prematurely).

Occasionally films which seem to flow out smoothly when first applied will still dry down with an orange peel effect. This is usually due to an improper solvent balance and is the result of uneven evaporation and the formation of vortices in the film. These vortices can frequently be seen with the naked eye, particularly in pigmented films. They usually result in pigment flooding, and the separation of the pigment particles outlines the six-sided figures formed by the vortex cells. Improved solvent balance is the best answer to this type of orange peel.

Bridging

Bridging occurs when the film contracts so much on drying that it pulls away from the deeper part of a recess. For example, in spraying a coffee table, lacquer might bridge over the moulding, and the film on drying would exhibit no adhesion at this point. In other words, the film has a loose, concave appearance rather than a sharp, tight angle.

Lacquers that are high in nitrocellulose, particularly high viscosity nitrocellulose, tend to exhibit this type of behavior. Too fast a thinner and too heavy a coat will also produce this condition. If the defect is discovered in time, it can usually be corrected by slitting the bridge with a sharp razor blade and adding some slow solvent to subsequent coats.

Dry Spray

Dry spray causes the work to have a sandy appearance. It is caused by:

1. Too much air pressure,
2. Solvents that are too fast,
3. Too high viscosity,
4. Holding the gun too far from the work or moving it too rapidly,
5. Solvents that are too lean.

Dry spray frequently occurs when an operator permits overspray from one part of the operation to collect on another part of the piece. If the nature of the piece is such that overspray cannot be avoided, the operator should keep the oversprayed areas ahead of the gun so that he can wet down the spray in subsequent passes of the gun, dissolving it into the film. If this is not feasible, dry spray may be redissolved by mist coating the work with a rich, slow thinner.

As in the case of blushing, however, it is best to have the rich, slow thinner in the formula in the first place and avoid the dry spray.

Poor Rubbing and Polishing

Like poor sanding, poor rubbing and polishing is usually the result of a film that is too soft. Here, too, it may be the result of too much film thickness, too slow a solvent, poor ventilation, too much plasticizer, etc. It may also be due to the use of resins that do not have the inherent ability to rub and polish. In general, resins which impart the greatest durability, such as the alkyds, have the least ability to rub and polish, and most lacquers have to be a compromise between these two properties.

If it is determined that a lacquer film is thoroughly dried, and it will still not rub and polish, the only remedy is reformulation.

Printing

Printing is the result of applying too much pressure to the film before it is thoroughly set. Printing usually occurs if the articles are prematurely packed. If the soft film comes in contact under slight pressure with any portion of the wrapping material, it will leave its impression in the film. A properly formulated and thoroughly dried film should be able to withstand packing pressure of two to four pounds per square inch after air drying overnight. If it does not, there may be solvent trapped in the film; the film may be too thick, the temperature of the warehouse may be too high (most films are quite thermoplastic when they are fresh), or the film may be too soft for any one of the dozen or so reasons mentioned previously. Sometimes these reasons are hard to find, but a careful search will usually smoke out the culprit.

Blooming

Blooming is the appearance of a smoky, hazy film on the surface of the finished piece. It will usually wipe off with polish but return again in a few hours. Blooming is sometimes caused by the use of an oil base rubbing or polishing compound on a film that is still soft because of retained solvent. Some of the oil apparently enters the film, and, being incompatible with the film-forming ingredients, sweats out later on the surface.

A bloom may also be caused by a slight incompatibility of the film-forming materials. This type of bloom can seldom be removed by polishing.

Discoloration

Discoloration usually takes the form of yellowing. All nitrocellulose lacquers will yellow eventually if exposed to strong sunlight due to liberation of small amounts of nitric oxide from the pyroxylin. Rapid and severe yellowing, however, is usually the result of a poor choice of resins or plasticizers. The formulator must know the color retention characteristics

of his ingredients. Yellowing is not too serious on dark colored woods, but the ever expanding use of bleached woods demands great care in the selection of non-yellowing film formers. There is no cure for yellowing except reformulation.

Checking

Checking is probably the number one nightmare of the furniture finisher, and it is particularly insidious because he never knows when it will strike.

We, at Interchemical, have developed a technique of rating the check-resistance of finishes in terms of their "distention potential." It makes a very interesting story, and one that I think you would like to hear because it takes the guesswork out of the checking problem.

Distention potential, hereinafter known as D. P. for short, is defined as the inate ability of a finishing system to absorb the stresses and strains created because of the dimensional instability of the substrate without physical destruction to itself. Or, in more practical parlance, it sets up numerical odds as to the probability of a finish checking when subjected to abnormal conditions of temperature or humidity.

To one thoroughly initiated in the art of furniture finishing the question immediately arises, "How can one do this with any degree of certainty?" Based on past experience, that is a very sound question. I should like to describe to you an instrument and a method of operating it that takes the checking problem out of the realm of the pari-mutuel and places it on a basis of scientific forecasting.

However, before getting into a discussion of the instrument and its operating technique, let us try to answer the question, "How much does a film have to stretch in order successfully to withstand the strains induced in it by the dimensional instability of the substrate in an everchanging atmospheric environment?"

The coefficient of thermal expansion of wood, e.g. expansion due to rise in temperature, may be in the order of 5×10^{-6} inches per inch per degree centigrade in the direction of the grain whereas across the grain the dimensional change is 40 to 50×10^{-6} inches per inch per degree centigrade. In simpler terms, this means that dimensional change across the grain is 8 to 10 times as great as that with the grain and that, across the grain, every linear inch will change, .00004 to .0005 inches for every degree of temperature change on the centigrade scale.

At first glance this may seem like very little, but a short session with pencil, paper and a slide rule quickly reveals the startling information that the dimensional change of a three-foot panel going from a factory or a warehouse room at 75° F. into a freight car or truck at 25° F. is more than one-eighth of an inch!

In addition to thermal changes we must consider the changes that are the result of variations in humidity. These changes are very real and very often unpredictable. In spite of the great lengths to which furniture manufacturers go to control the moisture content of their lumber, the danger of humidity checking is ever present.

The important thing in designing a finishing system for wood is to build into it a limit of elasticity that is substantially greater than the maximum dimensional change one might expect to encounter during the most adverse conditions. This calls for a film of great flexibility and tensile strength, both of which properties must be achieved without too much of a compromise with hardness, print-proofness and the ability to take a polish. To do this takes considerable formulating ingenuity, but an even neater trick is to know with certainty when the goal has been achieved.

Interchemical technicians recognized the crying need for a better method of predicting the check resistance of wood finishing materials and set about to devise ways and means for obtaining reliable scientific data that would enable them to make such predictions accurately and dependably. The result was an instrument known as the Interchemical-Mullen distentiometer.

It is axiomatic to state that in order to obtain reliable scientific data one must eliminate all variables and uncertainties. Since the wood, itself, is one of the greatest of these, any cold-check test based on wood as a substrate is bound to be extremely unreliable.

The ideal situation from a technical standpoint would be to apply the finish at a carefully controlled film thickness on a substrate that could be distended at a constant rate at a given constant temperature.

That is what we have attempted to do in the past in the conventional cold-check test where the finish is applied to a wood panel and subjected to alternate cycles of heat and cold; but, unfortunately, the direction and magnitude of the induced dimensional change cannot be controlled or predicted except in very general terms.

However, an acceptable substrate may be found in the form of very thin sheet copper of known and specified temper and ductility. When such a surface is coated with the film under test, the sheet and the film together may be deformed under carefully controlled conditions of temperature and humidity, and at a constant rate. The deformation is brought about by the application of hydraulic pressure to the under side of the sheet resulting in the formation of a hemispherical section, or "blister", the surface area of which represents a measurable increase of its original dimensions as a function of the height of the blister.

The whole assembly is mounted in a refrigerated cabinet where temperature is thermostatically controlled. The copper panel, after ageing for a length of time and at a temperature sufficient to permit complete solvent release (usually 16 hours at 120° F. in a forced draft convention oven), is placed in the cabinet and permitted to reach thermal equilibrium prior to testing. It is then clamped securely in a circular orifice in contact with a rubber diaphragm which closes one end of a cylinder containing the hydraulic fluid. The application of hydraulic pressure to the reverse side of the diaphragm forces it and the specimen upward through the orifice into a "bubble" or "blister" which takes the form of a segment of a sphere.

Prior to the application of hydraulic pressure, an Ames dial gage mounted integrally with the upper clamp jaw is set at zero with the needle resting on the surface of the panel in the exact center of the orifice. As the blister forms, the needle rises and one can read the height of the blister at the instant the film fractures. The end-point is positive, instantaneous and readily observed. Interchemical technicians have worked out a formula whereby the dial reading can be converted to percent increase in area, and at a D. P. reading of .150 the increase in area turns out to be about 10 percent.

For a given lacquer on a given panel, reproducibility of the test is within 2 percent for any operator. The machine controls its own temperature and its own rate of distention. Therefore, human element does not enter into the result except, perhaps, in the laying down of the films, and a technique has been devised for panel preparation which insures a minimum variation in film thickness. By this time you must certainly be wondering how a dial reading can be correlated with actual field performance. It can be done only by accumulating a wealth of data over many hundreds of tests on materials of established performance and subjecting these data to statistical analysis to determine what correlations exist. This task has been carried on

over a period of several years and has resulted in a classification of finishes into four groups as follows:

	Class I	Class II	Class III	Class IV
Distention Potential	Over 0.1000	0.0850 to 0.1000	0.0700 to 0.0850	Not over 0.0700
Per Cent Increase in Area Considered	2.8%	2.3% to 2.8%	1.4% to 2.3%	Not over 1.4%
Approximate Conventional Cycles on Wood	Excellent Infinite	Good 15 to 18	Fair 8 to 10	Poor 3 or less

In addition to being a watchdog over quality the distention potential tester has been the source of certain other valuable information when used as a research instrument.

By the systematic variation in the ratio of ingredients Interchemical technicians have learned just what to expect in the way of cold-check resistance as one ingredient is increased or decreased at the expense of another. The pattern of the fracture is also revealing as to the character of the film. A brittle film will fracture according to one pattern, a cheesy film will exhibit an entirely different pattern.

It has long been known that nitrocellulose in solution decreases in viscosity, particularly in warm weather. It is also known that as the viscosity in nitrocellulose decreases, so does its tensile strength, and, of course, lower tensile strength means lower cold check resistance. By means of the distention potential tester it has not only been established that the cold check resistance of a lacquer deteriorates on storage but the extent of this deterioration has been measured quantitatively and has been found to vary appreciably from one type of formulation to another. It is comforting to know what combination of ingredients will produce a lacquer that will maintain a high D. P. over as long a period as one could reasonably expect the lacquer to be stored. Furthermore, knowing the rate of deterioration for a given material, a safety factor can be built in to insure adequate performance after ageing.

Unfortunately, building a high degree of cold check resistance into a formula can result in low print resistance and poor rubbing and polishing properties. However, certain plasticizers impart greater cold check resistance than others and with less harm to other desirable film properties. By means of the distention potential tester, Interchemical technicians can quickly and easily determine the right kind of plasticizer and the optimum amount to use.

It has long been known that thick films are more prone to check than thin ones. By running the D. P. on a given material at three or four film thicknesses and plotting a curve, the D. P. at any given film thickness can be calculated.

Another bit of revealing data has been the effect of stearated sealers. The distention potential of sealer and topcoat have been run separately and then as a system and it has been found that no numerical correlation exists. The distention potential of the topcoat has more influence on the system than that of the sealer, probably because by the time the sealer has penetrated into the wood and half of it is sanded off, it represents only a minor part of the total film thickness.

However, the amazing observation has been made that a sealer and topcoat, each having a high D. P., when used together may yield a frightfully poor system whereas that same sealer with a different topcoat or the same topcoat with a different sealer may be excellent. Just what this happy relationship between sealer and topcoat may be has not been established, but that it exists there can be no doubt. There can also be no doubt of what may happen if it does not exist. It is extremely comforting to have a way of knowing in advance what these marital relations are likely to be.

Having considered the physical factors affecting the integrity of the finish, let us return briefly to some of the moral aspects.

During the developmental stage of any finishing material, the formulator is faced with the necessity of making a series of decisions. For example, here are a few:

1. What type of nitrocellulose shall I use?
2. What is the best resin to use?
3. What kind and how much plasticizer?
4. What is the best solvent combination?

Assuming that the formulator knows what he is doing in the first place, his decisions will be made largely upon his knowledge of the customer's requirements including whatever price information may have come to his attention.

If quality is the primary consideration, the decisions will not be hard to make. He knows what viscosity grade of nitrocellulose will give him an optimum combination of good distention, potential and reasonably high solids. These properties are at opposite ends of the scale, and his decision in making the compromise will be governed by his knowledge of in which direction the customer's emphasis lies. Price does not enter into this decision because all viscosity grades are priced approximately the same. High viscosity nitrocellulose yields higher distention potential and low solids, while the reverse may be expected from the low viscosity grade.

When it comes to the selection of the resin, however, there is a wide range of choices in both quality and price. Shall he pick a high melting point resin with fast solvent release and good rubbing and polishing properties? If quality is the prime consideration the answer is "yes". If price is an important consideration, the answer is "maybe". If price is the prime consideration, the answer is "definitely not".

This same sort of reasoning will apply to the choice of plasticizers and solvents.

Price and Quality Govern Formulator

Thus the formulator sometimes finds himself between a hard place and a rock. He wants to be honest with the customer and give him value received for each dollar he spends. He must also be honest with his employer, and formulate the material in such a way that it will satisfy the quality requirements of the customer and still not price his boss out of the market.

If the price situation is such that cutting some corners becomes necessary, then what corners shall he cut and by how much? To make this decision he must have a thorough knowledge of the customer's requirements, his production facilities and the type of end-use to which his product is subjected. If the product is sold in a geographical location where the temperature rarely drops below 60° F., cold check resistance might be unimportant and a corner that could be safely cut. On the other hand, humidity checking might be a real problem.

The point is that for the formulator to produce a finish of integrity, there must exist between buyer and seller a spirit of honesty and complete confidence. If the buyer is genuinely interested in doing business with the seller, then he should give him every opportunity that he needs to develop the information which will permit him to do an intelligent job.

The integrity of a finish begins with the user, because his supplier's judgment in formulating the materials will inevitably be colored by the customer's own attitude toward quality

Filler—The Theory and Technique of Application

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The function of wood filler, as used on furniture, is considered with the particular object of showing how the entire finish may be greatly affected by the quality maintained in the filling operation. The economic advantage of proper filling is pointed out. Preparation of the wood and application methods for better results in filling are discussed. A brief description is given of a method employed to compare results of filling by visual means.

Introduction

THE PURPOSE of this paper is to consider the functions of wood filler, and the methods of applying it to obtain best results, particularly in the field of wood furniture. It is not intended to cover the subject of formulation of different kinds of wood fillers, nor to discuss the relative merits of the products of various filler manufacturers. Granting that some fillers are better than others, at least for the particular purpose for which they are assigned, it is necessary for the user of filler, in order to get material best suited for his requirements, to give the supplier full information regarding the type of finish, the kind of wood, the finishing schedule, and plant conditions which might affect the finish. If the manufacturer of filler has been given complete information of the requirements to be met and the conditions under which the filler is to be used, it is his task then to produce a filler satisfactory to the user.

Should the filler manufacturer find that the requirements to be met are out of line from standard practices, or the conditions in the manufacturer's plant adverse to good results, he should so advise the user. The next step would then be to make a survey of requirements and conditions to determine whether or not changes in the finish or finishing schedule or in the plant set up would be practical. Many times minor and inexpensive changes can be made which would be far more effective in obtaining good results than for the filler manufacturer to attempt to evolve a freak product to meet extraordinary conditions. Please do not misunderstand the foregoing statement. I do not mean to infer that the manufacturer of filler should not attempt to fit his product into the user's scheme of things where it is feasible to do so. Nor, do I mean that filler manufacturers should not attempt to produce new and better products and to keep abreast of the ever changing pattern of furniture manufacturing and finishing. However, any radical changes in filler formulation and performance should be the result of thorough research and investigation and testing, which would require considerable time even though successful.

The Function of Wood Filler

Many articles or dissertations on the subject of protective coatings begin by stating that the purpose of such coatings is twofold;—to protect the surface and to beautify the object to which they are applied. Likewise, it can be said that wood filler has a dual purpose, aside from some possible specialty uses. One function is to provide a smooth surface on which to build a film of protective coatings. The other is to contribute to the desired color effect of the finished wood surface.

In using filler to provide a smooth surface, we do so for economy's sake. Surely it is much less costly to fill the pores and voids in wood in one operation than by using successive coats of film-forming materials. In fact, it is doubtful that a smooth surface over unfilled wood could be arrived at by multiple coats of finishing material, unless each coat were dried and sanded before the application of the following one.

In the color scheme of a finish, filler may have a widely varying role. In planning a finish for a suite of furniture, the color of the filler to be used should be considered at the start, since a filler of the wrong color can ruin an otherwise beautiful finish. In finishing certain types of wood which have a very pronounced figure or grain pattern such as hackberry or ash, it is often desirable to subdue the color of the filler to make it blend into the background color as inconspicuously as possible. For other woods, the attempt is made to emphasize or bring out the figure in the wood by using a filler with some contrast to the base color of the finish. As a rule in finishing furniture of traditional design, the filler is made enough stronger or darker in color than the background that it will not have a gray or muddy appearance. On other types of furniture, the filler may contrast with the background color by being lighter in color or of a different contrasting color altogether. An example of this is the limed oak finish or many of the toned finishes being used on mahogany, walnut, oak and other woods with large pore. These have been extremely popular during the past two or three years.

In years gone by, fillers were made not only to color the pores of the wood but, also, to stain the surface of the wood. This practice still holds to some extent, especially on oak office and school furniture. However, the usual practice in finishing household furniture is to have the filler color the pores while the surface of the wood is colored by stains, glazes, and often by color in some of the undercoatings such as washcoat and sealer. This latter practice aids clarity of finish, espe-

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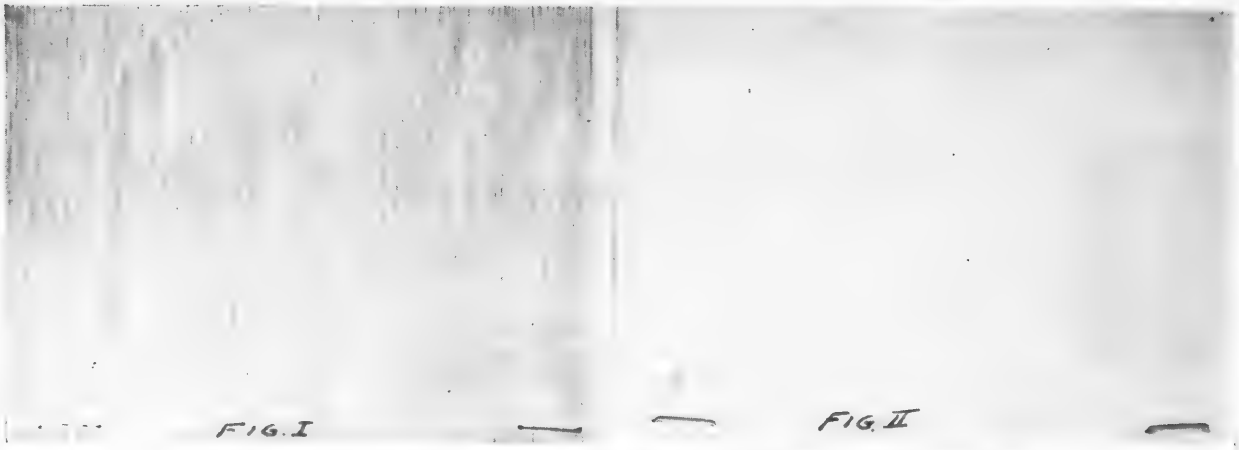

Figure 1 shows a panel filled using normal procedures, while figure 2 shows a panel filled by the double application and padding method.

cially in dark finishes, and provides better uniformity of color.

Results of Poor Filling

Too often, we have seen bad results from using too many coats or excessively heavy coats of sealer, lacquer or other top-coat materials. This is not done to replace the filling operation, but usually in an attempt to obtain a smooth surface over poorly prepared and poorly filled wood. The result of such practice might be print marks when the furniture is packed, due to the fact that the heavy coats did not dry properly on the finishing schedule; greater rubbing costs in cutting down extra material; poorer rubbing qualities of a film not properly dried; the danger of a film checking or cracking if it is too thick; and also the added cost of the excessive amount of material used and time expended.

Not all furniture or wood work requires a finish of great depth or fullness. Some of the highest priced furniture is purposely partly filled or not filled; even on woods with large pores such as mahogany, walnut and oak. This type of finish usually has little depth and lies close to the wood. However, a good body or depth of finish is required on most of the home furniture being made today. For the past few years, there has been a demand for furniture finish of great depth and high polish, particularly on suites of modern design; and this finish requires a smooth, mirror-like surface. Any open pores or partially filled pores detract greatly from its appearance. Many times such an appearance of "graininess", as it is often called, is laid to shrinkage of the coating materials, whereas the cause is poor filling. One after-result of poor filling is that the effect of the open pores cannot be eliminated in the rubbing process without causing the finish to be rubbed through in places.

It becomes evident then that poor filling can increase costs elsewhere in a finishing operation besides detracting from the appearance and salability of the finished product. The difference in cost of a good filling job and a poor one may not be great. It might mean only the placing of an inspector in the filler department, or perhaps an extra man or two in applying or padding filler.

Another defect due to poor filling may be pinholes in the final finish. Also, one of the most aggravating conditions in finishing wood is bubbling, or blisters forming in the sealer or top coats. There are, at times, other causes for bubbles or blisters in the top coat materials, but it has been the writer's experience that at least 90% of bubbling and blistering conditions have been due to improper filling. Any bubbling and blistering in coatings usually disappeared when the filling methods were corrected.

So far, this discussion on results in filling has dealt with the filling of the pores of the wood. There are also other phases to be considered. Filler not properly cleaned from the surface can cause a muddy or gray appearance in the final finish or obscure the figure of the wood. Filler improperly dried before coating may leave a grayish pore color which would detract from the clarity of the finish and likewise cause a muddy appearance. Aside from the harm to the beauty of finish caused by incorrect drying and poor clean up of filler, these faults in application may adversely affect the adhesion or toughness of the total finish.

Application Methods for Better Results

In attempting to prescribe the best methods for applying filler, it will be necessary to repeat good advice which has been given before by others, and much of which seems commonplace. However, there are certain phases of the process which should be particularly emphasized. Assuming that the user has the proper filler for the job, the various steps to be considered in applying the filler are as follows:

1. The preparation of the surface over which the filler will be applied.
2. Thinning and application of filler.
3. Padding in filler.
4. Clean up after padding.
5. Drying of filler.

1. Preparation of the Surface: The usual surfaces over which a filler is applied are: barewood (sized or unsized), a washcoat on barewood, a stain or toner, or a stain or toner which has been washcoated. The main requirements are that these surfaces, whether they be the wood itself or some finishing material such as stain, toner or washcoat, be properly dried and be as smooth as possible. To have excessive moisture in the wood, or solvents retained in finishing materials beneath the filler is to open the door for ultimate trouble in the final finish. This may show up as lack of adhesion of the coatings, poor filling, a cloudy gray finish, blisters or all of these defects. The surface should be smooth so the filler will cling only in the pores of the wood, leaving the surface clean. It is impossible to clean off filler from a rough surface without removing some which should be left in the pores.

When finishing woods of soft texture, particularly those species which do not sand readily to a firm, smooth surface, it is often advisable to size before beginning the finishing operation. This is especially true when filler is to be applied to the barewood. The size, usually animal or hide glue,

although other materials such as shellac or so-called bleaching lacquer may be used, is designed to stiffen the loose fibres on the surface of the wood so that they may be cut off cleanly when sanded. Also, by providing an even firm surface, sizing causes the wood to absorb color from stain or filler more uniformly than if it were unsized.

Glue is the most common substance used for sizing. It is applied by various methods such as spraying, sponging, roller coating, or brushing. It is most important that the right amount of glue is applied; that it is applied evenly; and that it is thoroughly dried before being sanded. The customary practice is to make a size by thinning one part of cabinet maker's hot liquid glue with from eight to eleven parts of water; the cabinet maker's glue usually being two parts of water to one part of flake or ground glue. It has been the writer's experience that ten or eleven parts of water is better than eight parts of water to one part of liquid glue. This provides sufficient water to wet and raise the fibres of the wood and to dry sufficiently fast to stiffen the fibres while they are still standing. Heavier applications of size tend to retard drying, fill the sand paper, and partially fill the pore of the wood, which is usually not desirable. A satisfactory method is to apply warm size (for better penetration and drying) evenly over the surface of the wood with a sponge.

Washcoats are usually used over stains or toners before filling, although in many instances the filler is applied directly over stain or toner. A washcoat may be said to be a thin coating of heavier substance or higher solid content than a size coating. It is generally made from shellac thinned with alcohol, or sealer or lacquer thinned with lacquer reducer, and may vary from 4% to 8% in solid content. Two main purposes of washcoats are to prevent filler, which is applied over it, from staining or darkening the surface or flake of the wood; and like a size coat, to stiffen and harden the fibre of the wood so that it may be sanded to a smooth even surface. The use of a washcoat was quite essential in the past when water stains were commonly used, due to the fact that water stains raised the grain and roughened the surface of the wood. Unfortunately, so-called non-grain-raising stains often belie their name in humid weather due to their hygroscopic characteristic; hence at times they also raise the grain of wood. It has become more or less standard practice, therefore, to use a washcoat and a sanding operation between the stain coat and the filler. For this purpose, when it is to be used over water stains or non-grain-raising stains, I prefer shellac as a washcoat rather than sealer or lacquer. This is because the alcohol in the shellac washcoat forms a constant boiling mixture with any moisture that might be present in the stain. The moisture then evaporates with the alcohol and is thus removed; which is not the case with sealer or lacquer washcoats, whose solvents are immiscible with water. If there is moisture present in the stain coat, and there usually is with non-grain-raising stains when used under conditions of high relative humidity, a shellac washcoat will produce a clearer finish than a sealer or lacquer washcoat. On the other hand, shellac washcoat dries slower than sealer or lacquer washcoats, and for that reason may not fit as well into fast finishing schedules. For a washcoat over a toner made from a nitrocellulose lacquer base, a sealer or lacquer washcoat is recommended because of faster dry and better bond between like materials.

Washcoats are used on barewood before filling, mainly when it is desired to color the pores of the wood with a minimum staining of the flake or surface of the wood.

It is necessary that washcoats be thoroughly dried in order that good sanding and good filling may be obtained. Washcoats not thoroughly dried before the application of filler will pick up color from the filler, causing lack of clarity in the finish. Also, they will cause poor filling and poor clean up of filler and may be a source of further trouble such as bubbling and blistering in top coats.

2. Thinning and Application of Filler: The standard practice for thinning filler is to use a petroleum distillate such as V. M & P Naphtha, mineral spirits, or so-called white gasoline. Although some finishing rooms still use white gasoline, most use V. M & P Naphtha or a mixture of it and mineral spirits. V. M & P Naphtha is to be preferred over gasoline because it can be bought on a specification basis and will be supplied within close limits to that specification for specific gravity, distillation range and solvency; whereas white gasoline has been found to vary considerably between succeeding shipments. Also, the use of white gasoline presents a greater fire hazard. Mineral spirits, being slower in evaporation than V. M & P Naphtha is normally too slow to be used alone. However, it is useful to mix with V. M & P Naphtha in order to adjust the evaporation rate of the thinner to meet varying climatic conditions. This is especially true in conveyorized finishing rooms where there is a definite time limit between the points where filler is applied and where the rubbing and padding begin; since for good filling, the filler on the surface of the wood should dry down to a certain point, as will be noted later, when it is rubbed and padded in. At the present time, V. M & P Naphtha and mineral spirits are available in almost every locality. Mineral spirits is also known as Stoddard Solvent or may be called dry cleaner's naphtha.

The amount of thinner to be used may depend upon the method of application, the type of wood and kind of finish or on local plant conditions. The opinions of different finishing-room foremen vary considerably on this subject. It might require some experimentation to determine the amount of thinner which will produce the best job.

Filler may be applied by brush, spray, or dipping. For large pieces of furniture, such as case goods and large tables, it is customary to spray or brush or, in many situations, both. For smaller objects, such as chairs or novelty furniture and small tables, it is common practice to dip the pieces in a tank of thinned filler.

For spraying, the proportion of filler to thinner may vary from five pounds of filler to a gallon to ten pounds to a gallon. Woods that are comparatively easy to fill will not require as heavy a mixture as those with large pores. More thinner is used for spray application than for brushing, because part of the thinner is lost by evaporation before it reaches the object to which it is being applied. The thinned filler should be strained before being sprayed.

For brush application, the proportions of filler to thinner may vary from seven pounds to the gallon to fourteen pounds to the gallon, depending again on the wood and the type of finish. If it is used too thin, there will not be enough filler deposited on the surface of the wood to fill up the pores when it is padded in. If used too heavy, it will be wasted, will cause the use of too much tow, moss, rags or other rubbing materials, and will be harder to rub and pad in.

In applying filler by dip on fine textured (close-grained) woods, such as gum, poplar, beech or tupelo, a mix of from four to six pounds of filler to a gallon of thinner is usually heavy enough. On coarse textured woods with large pores, the mix should be heavier, in which case it may vary from five to eight pounds of filler to a gallon of thinner. For best results, dip tanks should be constantly agitated to minimize settling of the heavier pigments.

A pressure tank equipped with an agitator is recommended for spraying filler. Low air pressure, of from twenty-five to thirty pounds at the gun, with about fifteen pounds tank pressure, should be used in order that the filler be applied wet with a minimum of evaporation of thinner during the spraying process. If the filler is sprayed from a gravity feed bucket, slightly higher air pressure at the gun, such as from thirty to thirty-five pounds may be used.

An E tip and needle with a No. 30 air cap is recommended when using a gravity feed bucket, and an E tip and needle with a No. 704 air cap when using a pressure tank. However, many prefer a No. 30 air cap for either gravity or pressure feed as it delivers a wetter coating of filler.

The filler should be applied quickly, evenly, and heavy enough that a thick pad of filler will be formed under the tow, moss or felt, or whatever material is used for padding the filler into the pore of the wood. It is good practice immediately following the spraying of filler to brush it across the grain of the wood using a long bristle brush. This not only assists in distributing the filler evenly over the surface, but breaks up any small air bubbles in the wet film due to the spraying operation, and allows the filler to run down into the pores of the wood.

3. Padding in Filler: The next step in the filling operation is the rubbing or padding of the filler into the wood. There are differences of opinion as to the proper time to start padding. Under normal conditions, the padding should begin soon after the filler flattens down; that is, when the wet appearance has disappeared from the surface but while it is still moist and soft beneath the surface.

There are various materials used to pad the filler into the wood, such as tow, sea moss, burlap and felt. The material should be soft enough and fine enough textured that it does not scratch the surface nor dig the filler out of the pores. A padding machine consisting of felt blocks mounted on a slowly revolving wheel does an excellent job of preliminary padding. Such a machine is moved back and forth across the surface while the revolving pads force the filler into the pores. Likewise, when the padding is done by hand, a circular motion, but moving across the grain of the wood is recommended.

The point to be emphasized is that the purpose here is to apply enough pressure so as to force the filler down to the bottom of the pores. This requires bearing down, especially if the padding is done entirely by hand. Sometimes, the operation is referred to as wiping filler, and too often it amounts to just that. Filler can be wiped off so that the pores appear to be filled level with the surface of the wood, yet it may not be packed firmly to the bottom of the pores. In such a case, when a heavy coat of lacquer or sealer is next applied, the solvents penetrate through the crust into the cavity beneath. Vapor is formed below which pushes out forming a bubble or blister in the coating or leaving a blow hole or pinhole in the film.

After the excess material has been removed in the preliminary padding either by machine or by hand, the surface should be gone over again by hand with a soft pad well covered with filler to make certain that each pore is packed full.

It is well known that the pores of different woods, as of various cuts of the same wood, differ greatly in size and shape. Some woods are known to be much harder to fill than others. Some pores are long and narrow and yet may be shallow or deep. On swirly cuts, there will be much end grain with small but deep pores. In the past, double filling was often times practiced on hard-to-fill woods. This was expensive and time consuming as it meant two complete operations of applying padding, clean-up and drying of the filler. Also, while it might have been some improvement over a single filled job, it many times did not give a satisfactory job. This was probably due to the fact that just enough hard dried filler was left in the pores from the first filling to prevent anchoring the filler into the pores the second time over.

However, there is another method of double filling, sometimes called prefilling, which does not cost a great deal more nor consume much more time than the ordinary single filling operation. The effective results obtained in eliminating "graininess", increasing the apparent build of coatings, and often in solving an exasperating condition of bubbling or blistering in coatings, have at times been almost amazing. Yet many seem to have no knowledge of this method or of the results obtained.

In this method, the filler is applied and given a preliminary padding usually with a padding machine. The piece then goes at once to a station where filler is applied again. This time a thorough padding operation takes place followed by careful clean up. The filler then is allowed its normal drying time before being coated. The theory behind this is that while the filler from the first application is still soft and workable, the added filler from the second application pushes it down and completely packs it into the pores. One application is usually by brush and the other by spray.

Oftentimes, one extra workman, with the use of a padding machine, can perform the preliminary application and padding operation. However, whether one, or two, or even three extra men are required, the improvement in results more than justifies the added cost. In fact, in most instances, savings in the total finish will be far greater than the added cost of this method of double filling, while the improvement in the finish is usually remarkable.

4. Clean Up After Padding: After the padding operation has been completed, the filled surface should be wiped across the grain of the wood to remove any excess of filler, and to make certain that the surface is left clean. Tow, or some heavy cloth, not too coarse, and preferably one that has been washed to remove sizing will do. Following this cross-grain wiping, the surface should be wiped gently with the grain of the wood with a softer cloth to remove any cross-grain streaks.

The final operation is to clean out corners, flutings, route lines or other hard-to-reach areas. A filler pick brush made of fibre bristles is satisfactory for this purpose on fine textured (closed grained) woods such as gum, maple, or cherry, but should not be used on coarse textured woods with large pores, as the bristles will remove the filler from the pores. Nor should filler be blasted out of corners or crevices with an air duster, as that method is quite certain to blow the filler from the pores of the wood.

5. Drying of Filler: To keep pace with the accelerated finishing schedules of recent years, various methods have been pursued in the effort to produce faster drying fillers. In some of these, fast drying oils or varnishes, or resins that dry by evaporation and polymerization have replaced the linseed oil and dryers of old-time fillers. In others, the vehicle solid content has been reduced to produce a filler which can be coated after a shorter duration of time. In still another kind, the liquids of the filler have little drying action, but are compatible with the solvents of the coating to follow. Although these have been successful for certain jobs and for certain colors, it is the writer's opinion that there is still much to be accomplished in making a perfect fast drying filler for normal air dry conditions. However, with the use of ovens or heat

(Continued on page 226)

Comparison of European and American Finishes

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European furniture finishes are made from the same basic materials used in the United States, but the methods of application vary considerably between factories on the two continents. In Europe all operations are influenced by the existence of high material costs and low labor costs. Cooperation between finishing material suppliers and consumers and the exchange of technical information between factories is not nearly as extensive in Europe as it is in the United States. In Europe the installation of conveyors and drying ovens is strongly influenced by government tax policies which limit expansion.

A COMPARISON OF EUROPEAN and American finishes shows both similarities and differences. The appearance of many European furniture finishes is similar to certain American finishes, but the materials and methods used to obtain such finishes are usually different. This paper is limited to a discussion of furniture type finishes in all price ranges.

Any comparison of materials and methods in different countries should be a statistical analysis of questionnaires distributed to the majority of operations under consideration or a scientific sampling of these operations; an analysis of the observations of a number of competent observers of these operations, or the conclusions of one observer who has visited a number of the operations. Unfortunately, the writer of this paper does not have the results of a questionnaire from the majority of the operations or even a scientific sampling; but this paper does report on the observations of finishes by a number of experienced technical men[1] and the writer's own observations made on thirty-three factories visited in Europe in 1952[2] and many visited in the United States from 1950 to 1953.[3]

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Finishing Systems

In Europe the following procedure is customary on expensive furniture. A water stain is applied by brush; a wash coat is brushed or sprayed on and sanded when dry. Filler (optional) is applied by brush and padded with cloth by hand. Sealer is applied by spray gun and sanded when dry. Glazing stain is applied by brush or a lacquer toning stain is applied by spray gun. Two or three coats of lacquer are applied by spray gun. Rubbing and polishing is done by the "pull-over" process. This process consists of rubbing the surface with a cloth saturated with a mild solvent which softens the finish and pulls the high spots down into the low places to produce a smooth surface. In the United States the procedure is the same except in the first operation a non-grain raising stain is usually applied by spray gun, filler is generally applied to open pored woods, and rubbing and polishing is almost universally done by cutting down with fine sand paper and buffing with a fine grinding compound. Finish coats are frequently dried in ovens at elevated temperatures in the United States; but this is not common in Europe.

Cheap furniture is frequently finished in Europe by applying sealer with brush or roller as a first coat, sanding, applying one coat of lacquer by spray gun, and rubbing with steel wool or a limited polishing with a variation of the "pull-over" process. In the United States the cheap furniture is nearly always stained, open pored woods are filled, sealer is applied by spray gun and sanded, and a natural varnish is frequently used as the top coat. Rubbing is not usually done except on tops of certain lines.

Medium priced furniture includes all the variations of finish between the two extremes listed above in both Europe and the United States. However, there appears to be very little medium priced furniture in Europe, while much of the United States output is in the medium price field. Although the variations in the different prince ranges are interesting, an analysis of each step in the finishing process gives a better basis for comparing the European finishes with those used in the United States.

Comparison of Each Step in Finishing Process

Although not strictly a finishing operation, the preparation of the wood plays such an important part in producing a good finish that "sanding" will be discussed as the first step in the finishing process. European factories tend to operate cutting machines at slower feed rates, using more skilled operators, than is usually done in the United States. The European machining method produces wood parts which are easily sanded to a smooth surface. In addition, European face veneers are usually cut 1/40 inch thick rather than the 1/28th inch standard in the United States, but the European

[1] *Furniture Finishing Manual*, North Carolina State College School of Forestry Technical Report No. 6, August 1951.

[2] Johnson, E. Sigurd, "Observations on West German Furniture Production Methods in 1952", Journal of the Forest Products Research Society, Vol. III, No. I, February, 1953.

[3] Johnson, E. Sigurd, "Finishing of Wood Furniture in Southeastern United States Factories", Unpublished, Mimeographed report, School of Forestry, Duke University, May, 1950.

veneers are more smoothly cut. Because of smoothly cut surfaces and thin face veneers and because the "pull-over" rubbing and polishing process can cover up minor defects that have not been removed by repairing and sanding, European furniture factories usually do less sanding than is done by comparable American factories.

A typical American factory might sand veneered panels by endless bed drum sanding with No. ½, 0, 2/0 size grits, rough belt sand with 3/0, glue size, and polish belt sand with 5/0. Mouldings might be sanded with a No. 2/0 cloth-backed abrasive belt using a formed block. Hand sanding is usually limited to touch-up work and possibly a light standing of tops only with fine sandpaper immediately before staining. If a European factory uses an endless bed drum sander it might have only two drums. The operation would be followed by one belt sanding rather than two. Frequently the drum sanding operation is omitted and two belt sandings are used. Glue sizing is frequently omitted. The final grit size used is coarser than is usual in the United States, but the furniture is always completely hand sanded before finishing. Mouldings are usually sanded by hand only. Consequently, the European sanded parts have smooth surfaces, but frequently are not as flat or as well prepared as surfaces, properly sanded, in the United States.

The first operation in the finishing room normally is staining in both Europe and the United States. Very little bleaching is done in Europe; and in the United States bleaching is being replaced to a large extent by semi-transparent toners. The application of a white pigmented toner for a first coat, as used in the popular American modern "seafoam" finish, was not evident in Europe as late as the fall of 1952. Except for this particular type of modern finish, the first coat is usually a non-grain raising stain in the United States. Some water stains are still used and some pigmented wiping stains and oil stains are used for special applications, but they are in the minority. In Europe, the first coat is usually a water stain although there is some use of combined stain and filler and other type stains for special applications. Where they are advantageous, equalizing and sap stains are used on both continents. Non-grain raising stains are seldom used in Europe because of the high material cost; and the lower price of labor permits the hand sanding of raised grain caused by water stain. Stains are usually applied by spray gun in the United States and frequently in England, but usually by brush in the rest of Europe.

On both continents wash coating consists of a four to ten percent solids material applied after the stain to hold erect the raised grain fibres so they can be cut off to a level surface by hand sanding. Both thinned lacquer sealers and shellac dissolved in alcohol are used as wash coats. Although wash coats are practically alway sprayed in the United States, they are frequently applied by brush in Europe. On both continents sanding is done with fine sandpaper by hand or by hand power sanders.

In the United States filler is generally applied to large pored woods. The filler is usually thinned with V M & P naphtha or white gasoline and applied by spray gun. It is then allowed to flash, rubbed across the grain with coarse burlap, jute or tow, and wiped clean with a soft cloth along the grain. Although filler is frequently sprayed in England, in the rest of Europe it is usually applied by brush in a very thick mixture.

The fillers used in Germany appear to be of very simple formulation. It is extremely difficult to obtain a complete filling job with these materials. For this reason and because of the public's desire for clear appearing pores in certain finishes, the filling operation is eliminated in many European finishes. On low priced merchandise and some high priced, the product is shipped completely finished with unfilled pores. However, the high polish finish obtained by the "pull-over" process fills the pores so that a smooth surface is obtained without the use of the conventional filling operation.

In both the United States and Europe sealer consists of a nitrocellulose lacquer modified for sanding and is applied by spray gun. However, where the sealer is used as a first coat in Europe, it is usually applied by brush or by roller coater. In both continents sanding is done by hand and by power driven hand sanders.

Shading and glazing stains are used in the same way in Europe as they are in the United States. Shading stains are thinned lacquer containing dies applied by spray gun for highlighting and deep color effects. Glazing stains are pigmented stains that are brushed to obtain high lighting, antiquing, and deep color effects.

In Europe the standard top coat process is the application of one or two coats of nitro-cellulose lacquer by spray gun. Although the same system is the most common in the United States, there is considerable use of hot lacquer, urea-alkyd varnish, and regular varnish. Hot lacquers are not common in most European countries, but are used frequently in the Scandinavian countries. Urea-alkyd resin varnishes are just beginning to be used in most European countries.

The formulation of lacquers appears to be different in the two continents. Like our materials, the European lacquers contain nitro-cellulose, resin, plasticizer and solvents, but tend to have fewer ingredients than the United States lacquers. The European lacquers are formulated for the "pull-over" process of rubbing while the United States lacquers are formulated for rubbing by cutting down with fine sandpaper and buffing to a high polish.

The final finishing process of rubbing and polishing is entirely different in Europe from the process used in the United States. We cut the high places down by the use of fine sandpaper with thin oil as a cutting lubricant. After removing the oil with a clean-up solvent, we polish the level surface by buffing with a cloth or lambswool buffer and a finely divided abrasive polishing compound. In this method it is very important that the wood surface be sanded to a level plane and that all pores and imperfections be well filled before the top coats are applied.

The typical European "pull-over" method of rubbing consists of rubbing the lacquer surface with a cloth dipped in a mild lacquer thinner so that the high spots are pushed down into the depressions. Frequently the thinner mixture contains solids so that material can be added to fill up any holes or depressions. This "pull-over" method requires much more time than the United States method of cutting down and buffing. Consequently, there have been mechanized rubbing machines developed to speed up this tedious process. Because of the long time spent on each part and the ability of the rubbing material to fill holes and depressions, surfaces do not have to be as well prepared as they do in the United States method.

In Europe there is a great variation in the appearance of different parts of furniture according to the time that is spent on each part. An end panel may be smoothed with only a few minutes of rubbing while a front may be rubbed for an hour to obtain a perfect high polished surface that will remain mirror-like for years. Mouldings and carvings can be high polished by this method if desired. The mild solvent is sometimes used between lacquer coats for leveling the surface before the application of the next coat. Since

th "pull-over" process not only levels high spots, but also fills holes, it is absolutely essential that the final polishing of this process be delayed until the lacquer top coat has completed any shrinking that may take place. Some factories wait two to three weeks after the last lacquer coat application before the final polishing is completed in the "pull-over" process. The "pull-over" process takes much labor, but a nicely rubbed surface can be produced with a thinner lacquer coat than is possible with the American method.

A number of Scandinavian factories use a variation of the United States method by cutting the lacquer film to a flat surface with a thin steel blade called a "zie klinge" and then buffing to a high polish with a rubbing compound. The use of the "zie klinge" requires a certain amount of manual dexterity and skill to avoid scratching the lacquer surface. The sharpening of the steel blades is extremely important and is actually a major drawback to its wider use, although a company in Denmark now manufactures an automatic grinder for sharpening these blades.

Equipment

The finishing equipment used in European furniture factories is practically identical to United States equipment. Spray booths, pressure tanks, hoses, transformers, and spray guns are similar on both continents. Both American and European plants use reciprocating power hand sanders, but German plants use rotary power hand sanders not usual in the United States. The finishing rooms tend to be smaller in Europe and do not usually have drying ovens or conveyors. However, a number of large factories have recently installed or are planning to install conveyors and drying ovens. In both the United States and Europe all types of conveyors have been tried, but the trend is toward the use of platform type floor power conveyors.

General

A number of specific differences between European and United States finishes have been described in this paper. Some of the differences are caused by consumer preference, but most of the differences in materials and methods are caused by the relationship between material and labor costs. European lacquers and other finishing materials cost 25% to 50% more while much of the European labor costs 60% to 75% less than American. This cost relationship is one of the major reasons for the use of water stain rather than non-grain raising stain, brushing many coats rather than spraying, the "pull-over" rubbing process, and the transporting of furniture by hand rather than by conveyor.

Although it is not actually a finishing material or method, one difference apparent in some European countries is the lack of cooperation between factories compared with the system common in the United States. In this country most finishing material suppliers have an excellent staff of competent service men who assist their customers to maintain control of the quality of finish being applied. Frequently, in cooperation with the finishing material factory laboratory, the service men develop complete new finishes for their customers. The service men constitute an extension of the material suppliers facilities into the customers plants. The United States material suppliers do their best to make materials that are specifically formulated for the product and working conditions of a particular factory. Although there are service men in Europe, the cooperation between suppliers and customers is not nearly as complete as it is in the United States. The difference in the degree of cooperation is also apparent between furniture factories themselves. In our country, it is common practice to exchange technical information through factory visits and trade association or technical society meetings. Such practice is not common in Europe.

Conclusion

Although there are differences, European and American finishes are basically the same because the materials are of the same type and many of the methods are similar. If the European consumers should begin to use American styles and the relationsn. of European material costs to labor costs became more like the American relationship, it is probable that finishes would become almost identical on both continents. The change to conveyors and drying ovens would probably be slow because it is very difficult to obtain capital for expansion in most European countries. Investment capital is scarce, interest rates are high, and income taxes are so high that it is extremely difficult to pay for capital expansion out of earnings. Let us hope we do not permit government taxation or other policies to restrict expansion and our ability to improve methods in the United States.

TECHNICAL SESSION VI—Tue., June 16, 1953, 2:00 P.M.

Subject: Wood Composition Board

Chairman: George G. Marra

Recorder: Richard Burkhart

Potential Raw Material Supply for Wood Fiber Products

E. E. MATSON

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The potential raw material supply suitable for wood fiber products is enormous. Fiber products can be manufactured from residual wood developed at manufacturing plants and from material left in the woods after logging. Recently the amount of residual wood used in the manufacture of pulp and fiberboard has increased notably. However, the volume still available justifies a greatly expanded wood fiber industry.

THE POTENTIAL RAW MATERIAL supply suitable for wood fiber products is enormous. Since these products can be made from all species and types of wood, one might answer the question as to potential wood supply by simply quoting standing timber volumes of the United States. Such an answer, of course, would be meaningless because the timber supply must fulfill the demand for all types of wood products, whereas wood fiber products can be made from small pieces of wood of the type developing as "waste" in manufacturing lumber or other primary wood products.

Perhaps the most realistic approach would be to consider the potential supply as the volume of wood that is unsuitable or uneconomic for primary products. This includes material from three sources: logging operations, manufacturing operations, and cull trees or small trees which are not normally included in inventories of standing timber.

The only complete set of national figures on the amount of residuals developed annually is found in the Forest Service Reappraisal Report[1] for the year 1944. The equivalent of 39 million cords of logging residuals and 19 million cords of chippable manufacturing wood residuals were developed in 1944 (Table 1). In addition, the primary manufacturing plants produced a total of 17 million units of sawdust per year (one unit equivalent to 71 cubic feet of solid wood). Utilization practices have improved considerably since then, and, no doubt, the situation today is somewhat different. We will soon know just how much of a change there has been during the past nine years, for a survey similar to that of 1944 is planned for the calendar year 1953. It is expected that this survey will show a marked change of logging residuals produced per thousand board feet of logs and a lesser change in manufacturing residuals. Meanwhile, we can make some fair estimates of the material available from the three main sources.

[1] Wood waste in the United States. Report 4 from a reappraisal of the forest situation. 1947.

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Logging Residuals

Much wood is left behind in logging operations that would be suitable raw material for wood fiber products. This residue consists partly of defective logs and low-quality logs that cannot pay the cost of transportation to manufacturing plants. In addition a great amount of broken wood of various sizes develops in all logging operations.

Falling, the first step in timber harvesting, is usually associated with considerable breakage of otherwise commercial material. The amount may vary from practically nothing in young stands on gentle topography to several thousand board feet per acre in large old-growth stands in rough, rocky topography. Some operators logging on rough topography in the West even go so far as to use tractors and cables to pull the trees so that they can be felled uphill, thereby minimizing breakage. In some cases they have reduced falling breakage by as much as 8000 board feet per acre. Falling also damages smaller trees in the understory. In other phases of logging, from skidding to delivery at the manufacturing plants, some breakage de-

Table 1—RESIDUAL WOOD PRODUCED IN THE UNITED STATES IN 1944

Area	Chippable wood: Logging	Chippable wood: Primary M cu. ft.	Chippable wood: Total	Equivalent in M cords M cords	Sawdust M cu. ft.
North:					
New England	129,700	56,100	185,800	2,323	4[illegible]900
Middle Atlantic	160,600	61,300	221,900	2,773	5[illegible]800
Lake	200,200	51,700	251,900	3,149	2[illegible]800
Central	292,600	76,000	368,600	4,607	3[illegible]500
Plains	3,600	1,700	5,300	[illegible]	[illegible]300
Total	786,700	246,800	1,033,500	12,918	17[illegible]300
South:					
South Atlantic	297,300	207,300	504,600	6,307	1[illegible]000
Southeast	557,200	383,900	941,100	11,764	2[illegible]500
West Gulf	386,000	237,600	623,600	7,795	1[illegible]900
Total	1,240,500	828,800	2,069,300	25,866	5[illegible]400
West:					
No. Rocky Mtn.	59,400	44,300	103,700	1,296	[illegible],300
So. Rocky Mtn.	14,400	15,700	30,100	376	1[illegible],400
Pac. Northwest	926,600	348,500	1,275,100	15,939	41[illegible],600
California	126,900	71,100	198,000	2,475	9[illegible],100
Total	1,127,300	479,600	1,606,900	20,086	57[illegible],400
United States	3,154,500	1,555,200	4,709,700	58,870	1,3[illegible],100

velops but not nearly as much as in the falling operation. This broken material plus the uneconomical portion of the tree leaves a sizeable amount of wood on the ground after logging.

Throughout the country more of the small, defective, and poor-quality logs are now hauled to manufacturing plants than was the case in 1944. In the West prelogging is being done to salvage the understory that otherwise would be damaged in the logging of big timber. Relogging to clean up cut-over areas is now common practice in many regions, and much timber is salvaged today that was considered unmerchantable a few years ago.

A number of surveys were made recently in the Northwest and Lake States to determine the amount of wood left by the present-day loggers. These surveys indicate that the amount of wood left today is only about one-half what it was in 1944. This situation may not be true for the entire country. However, if it were true, there still would be about 19 million cords of wood left each year on logging operations.

Although the raw material supply from logging residuals is great, it is not expected that this material will be utilized first for wood fiber products. Logging residuals are expensive to collect and transport because they are, ordinarily, of smaller sizes and contain more defective material than the average for the timber stand. Unutilized wood developed in manufacturing operations is more centrally located and so offers a cheaper raw material supply.

Primary Manufacturing Residuals

In manufacturing a log into a wood product, residuals develop in the form of sawdust, shavings, slabs, edgings, trim and veneer clippings, cores, and mismanufactured products. The amount may vary considerably by types of operation and products, but the volume produced per thousand board feet of logs is more uniform than in harvesting operations.

Lumbering, being the largest wood-using industry, produces the most manufacturing residuals. In 1944 the Reappraisal report showed that an average of 70 cubic feet of wood residuals were produced per thousand board feet of lumber sawed. Of this amount, 37 cubic feet was chippable material and the other 33 cubic feet was sawdust and shavings.

According to a number of recent surveys the amount of manufacturing residuals produced per thousand board feet of logs is now approximately the same as 1944. The total of this raw material produced by the entire country would be somewhat higher than in 1944 because the production of lumber, plywood, and other products has increased since that time.

Material from Cull and Small Trees

In addition to logging and manufacturing residuals there is an enormous potential raw material supply in the form of small trees, that die each year in young stands because of crowding, and cull trees. If the cull trees in the South were liquidated over a 15-year period at least a million cords of additional softwood could be produced annually from this source, according to H. R. Josephson.[2] It has been estimated that about 7 million cords of additional wood could be produced annually from improvement cuttings from timber stands in the Northeast. In the Douglas-fir region of the West it is estimated that natural mortality in young stands amounts to approximately one cord per acre per year. There are approximately 8 million acres of these young timber stands and the total volume of wood lost on this area amounts to 8 million cords per year.

Therefore, it is evident that the potential raw material supply from logging and manufacturing residuals and from improvement cuttings in our timber stands may exceed 70 million cords a year. The chief obstacle to an expanded wood fiber industry, then, is not raw material supply. Markets for the product and the economics of manufacture are more serious problems.

Competitive Uses for Raw Material Supply

A number of products are now made partly or entirely from wood residues. This use should expand since wood residue is a much cheaper raw material supply than can be obtained from logs suitable for primary manufacture. Some of the chief uses are as follows: fuel wood, hogged fuel, charcoal, pulp chips, hardboard, insulation board, cut stock and lath. These are competitive uses because they may all draw from the same raw material supply. Hence, in any local situation, the economics of a prospective residue-using enterprise will be affected by the extent to which other outlets for available raw material are being exploited.

Fuel Wood: The biggest single use for residual wood is for fuel. According to the Reappraisal Report the equivalent of 2320 thousand cords of logging residues and 12,300 thousand cords of manufacturing by-products were used for fuel during the year 1944. Undoubtedly, most of the fuel wood obtained from the logging operations was used for domestic consumption. Some of the material from manufacturing plants was also used as domestic fuel. However, the greater part of it was probably used for the production of power at commercial plants. The trend during the last few years has been toward a reduction in the use of wood for fuel—both in commercial plants and for domestic use. Although no estimates are available, it is assumed that the amount of wood used as fuel at the present time is less than that shown for 1944.

Hogged Fuel: The 1944 report also shows that the equivalent of 10 million cords of sawdust, shavings, and other fine material was used for fuel. Most of this material was used in the primary plant to produce power. However, a small amount was used for domestic fuel, and some was transported to other commercial plants for the production of power. The biggest use of sawdust and hogged fuel is concentrated on the West Coast where there are large numbers of sawmill and plywood plants and where there is cheap water transportation.

Hogged fuel, although not a very high value product, offers a good opportunity for the disposal of manufacturing waste. All sizes of wood material including the bark is suitable for hogged fuel. Many pulp mills, power plants, and similar installations are equipped so that they can burn either hogged fuel or oil in their boilers. At these boiler plants a unit of hogged fuel is considered the equivalent of 2½ barrels of crude oil. At present the price of crude oil is $2.10 a barrel and hogged fuel is approximately $3.00 a unit delivered. The cost of delivering varies but averages about $1.25 a unit. In other words, the value of the hogged fuel at the sawmill is about $1.75 a unit. The small amount of hogged fuel and sawdust sold in western states for domestic use costs about $5 a unit delivered.

Charcoal: Charcoal production offers a good possibility for utilizing wood residue as odd size pieces of wood including bark are suitable. Both hardwood and softwood can be used although the more dense hardwoods give a higher yield and, therefore, are the principal species utilized.

Charcoal production has decreased considerably during the past twenty

[2] Josephson, H. R. 1953. Use of woods and mill residues for pulpwood. (Paper presented at annual meeting Amer. Pulpwood Assn. N. Y. Feb. 18, 1953.)

years. According to a report[3] by the Department of Agriculture approximately 300 thousand tons were produced in 1951.

Henry W. Hicock of the Connecticut Agricultural Station gives the following yields from the various types of wood in his report[4] "Small rectangular charcoal kilns:"

Seasoned hardwood—900 pounds per cord
Green hardwood—750 pounds per cord
Softwood—650 pounds per cord

To produce 300 thousand tons of charcoal requires in the neighborhood of 700 thousand cords of wood. Not all of this wood comes from residual material, but all charcoal could be produced from waste wood and, therefore, this product offers a good opportunity for using unutilized material.

Pulp Chips: Outside of fuel, the biggest use of residual wood is for pulp chips. Josephson's report previously mentioned shows wood requirements for United States pulp mills have increased an average of more than one million cords annually during the last 10-year period. Although this increase has been made up chiefly from growing timber, there also has been an encouraging expansion in the utilization of wood residues.

In 1951 pulp mills in this country consumed 25 million cords of pulpwood of which 16 percent or 4 million cords, was derived from milling and logging residuals. Pulp mills in the South consumed 14 million cords of pulpwood of which 1.8 million cords was logging residuals and 20 thousand cords were obtained from sawmills. Pulp mills in the northern states obtained five percent of their 6½ million cord requirements from logging residuals. In the West approximately 30 percent of the annual pulpmill requirements of 4.6 million cords of softwood pulpwood comes from residual material.

The opportunity for utilizing wood residues is best in the West because much of the unutilized material from logging and manufacturing is found in this region and it is more concentrated than in other regions. The use of pulp chips obtained at sawmills and plywood plants has grown spectacularly during the last few years. In 1950 pulp chips equivalent to 660 thousand cords of pulpwood were obtained from western manufacturing plants. In 1951 the amount had increased to approximately one million cords, and for 1952 it has been estimated that the amount was probably close to double that used in 1950.

[3] Beglinger, Edw. Production and Uses of Charcoal. U. S. Dept. of Agric. Year Book 1950–51. p. 810–813.

[4] Hicock, Henry W. Small Rectangular Charcoal Kilns. Northeastern Wood Utilization Council. Bul. 37. p. 24. Jan. 1952.

Table 2—CHIP RECOVERY EXPERIMENT DRY WEIGHT PER CORD

Source of chips	Units per cord	Pounds dry weight per unit	Pounds dry weight per cord
Peeler cores	1.258	2,216	2,787
Rough lumber sizes 1 x 4—8 x 8	1.454	2,536	3,687
Mill waste random	1.232	2,355	2.901
Long length edgings	1.167	2,168	2,530
Small logs (4"—20" diam.)	1.127	2,210	2,490
Large logs (over 20" diam.)	1.096	2,360	2,587

In Oregon and Washington alone there are now over 100 chippers set up at sawmills and plywood plants. Plywood plants are producing from waste veneer about 0.4 of a unit of chips from each thousand feet of logs. Sawmills picking barkfree wood from the waste conveyor are getting about one-fourth of a unit of chips from each thousand feet of logs. Those mills with hydraulic barkers are obtaining approximately 0.6 of a unit per thousand feet of logs. A unit of chips contains approximately 71 cubic feet of solid wood or roughly 90 percent of the wood found in a cord of 8-foot unbarked pulpwood.

Most plywood plants in the West are already making pulp chips out of material not suitable for plywood. Many additional sawmills would like to get into the chip business, but it is doubtful that this business can be greatly expanded without additional sulphate pulp capacity. Douglas-fir, which requires the sulphate process, is the chief species in the vicinity of the pulp mills of the Northwest. At present these Kraft mills are utilizing chips produced from manufacturing waste as their main raw material supply. The use of chips has greatly reduced the market for Douglas-fir pulpwood and low grade logs. There is still a good market for hemlock chips to be used in sulphite mills, but most sawmills saw this species along with Douglas-fir and, therefore, must sell the chips to a sulphate mill.

The raw material supply in the form of unutilized material at manufacturing plants and in the woods is sufficient to justify a considerable expansion of sulphate pulp production in the West.

Hardboard: Another use for mill residues similar to pulp chips is as raw material for hardboard production. Production of this material has expanded greatly during the last five years. According to a report[5] prepared by Wayne Lewis, there were only three plants in 1948 producing 280 thousand tons or 750 million square feet of ⅛-inch hardboard per year. At the end of 1953, Lewis forecast, there will be 16 plants, producing 630 thousand tons or 1.74 billion square feet of ⅛-inch hardboard. Not all hardboard plants use residual wood as a raw material. The largest producer of hardboard uses cordwood at its plant in the South and lowgrade commercial logs at one in the West. However, the remaining plants in the West are set up to use wood residuals from sawmills or plywood plants.

The western hardboard plants which are based on residual wood as a raw material will produce approximately 590 million square feet of ⅛-inch hardboard per year. These plants figure it takes approximately 800 pounds (dry weight) of softwoods to make a thousand square feet of ⅛-inch hardboard.

According to a study made by one company it was found that a cord of Douglas-fir contains approximately 24 hundred pounds of dry weight wood. On this basis, the 15 western mills plan to use an equivalent of about 230 thousand cords of wood residuals annually.

Many types of mill residuals are utilized by hardboard plants. A test was made by one company to determine the volume of wood obtained from various materials. The results of this test for bark-free Douglas-fir are shown in Table 2.

One company in Oregon producing 50 million square feet of ⅛-inch hardboard per year utilizes unbarked slabs from their sawmill. Since bark is acceptable, this process will open up a market for some of the enormous amount of material that is lost annually through natural mortality in crowded young forest stands.

Insulation Board: The raw material requirement for insulation board is very similar to that of pulp and hardboard. The Department of Commerce reports 926,000 tons of insulation board was produced during 1951. Since insulating board weighs an average of 750 pounds per thousand square feet, ½-inch thick, the production for 1951 equals approximately 2,470,000 M square feet.

At present about three-fourths of this board is made from wood fiber and it is expected that it probably will continue to be the major source of raw material for this product.

[5] Lewis, Wayne C. The hardboard industry in the United States. Journal of the Forest Products Research Society. p. 3–6. Nov. 1952.

Therefore, insulation board plants will compete with pulp and hardboard manufacturing plants for wood chips.

Cut Stock: Cut stock offers a market for the large-size byproducts that develop at manufacturing plants, particularly sawmills. A great many small pieces of lumber are used for a large number of items falling generally into the classes of: factory house group, millwork group, household equipment, toys, agricultural implements, moldings, and a host of similar products.

It is difficult to estimate how much wood is used annually for these products. Cut stock consumption for 1948 has been estimated at at least 190 million board feet. A portion of this volume was produced from slabs and edgings at sawmills.

The consumers of cut stock require that the material be well seasoned, be cut to exact size, and they prefer the soft pine species. Cut stock produced by mill men from residuals often has not met these specifications. Manufacturers have therefore preferred to buy seasoned lumber and cut it to exact size at their fabricating plants. If the volume of cut stock produced from mill residuals is to be expanded, more attention will have to be given to producing a product acceptable to the fabricating plants.

Lath: Lath has been produced for many years almost entirely from slabs at sawmills. A little over half of the annual lath production comes from the states of Oregon and Washington. At present lath produced in these states sells for about $12 per thousand pieces at the sawmill. Production of lath has decreased during the past several years. In 1942 production amounted to 307 million pieces and in 1947, the date of the last available national figures, the amount was slightly less than 200 million pieces. Because there are several substitutes for lath, the output of this product is likely to continue to decrease. Sixty lath equal one cubic foot. Assuming production at 200 million pieces a year would mean that 3,330,000 cubic feet or about 41.6 thousand cords of residual wood go into this product annually.

Other Products: Residual wood can be used in numerous other products, such as: sawdust for soil conditioners, pres-to-logs, molding fiber, wood flour, and products from wood hydrolysis. But the volume of wood residuals that will be used as a raw material for these products is small and should not offer serious competition for available raw material in the foreseeable future.

Table 3—PRICES OBTAINED FOR BYPRODUCTS BY DOUGLAS-FIR MILLS

Product	Unit of measure	Solid cu. ft. per unit of measure	Value at mill	
			per unit	per cu. ft.
Fuelwood	cord	90[1]	$ 5.75	$0.06½
Hogged fuel	unit[2]	71	1.75	0.02½
Sawdust (domestic use)	unit	71	3.50	0.05
Pulp chips, Douglas-fir	unit	71	7.50	0.10½
Pulp chips, Hemlock	unit	71	15.00	0.21
Lath	M pcs.	16	12.00	0.65

[1]Approximately 27 percent bark.

[2]A unit equals 200 cubic feet of gravity-packed material.

Summary

Enormous supplies of raw material suitable for wood fiber products can be obtained from logging and manufacturing residuals and from small and cull trees that are not included in forest inventories. No exact figures are available on the annual potential supply available from this source although it is conservatively estimated to be at least 70 million cords.

From these residuals some 14,620,000 cords of coarse wood and the equivalent of 10 million cords of sawdust and shavings are used annually as fuel. For pulp chips another 4 million cords are used. During the present year the greatly expanded hardboard industry will use about 230,000 cords of residual wood and the volume going into softboards will probably be double that amount. Numerous other products are being made from logging and manufacturing residuals and it is expected the volume utilized will continue to increase.

Large investments have been made by industry to make this wood suitable as a raw material for other products. Barking and chipping equipment at sawmills and plywood plants are excellent examples of what can be done to produce a suitable raw material for another industry.

Residual wood develops wherever timber is harvested. However, opportunities for obtaining a raw material supply are best in the western states. In this area the volume of residual wood is more concentrated than in other parts of the country. Douglas-fir operators have been particularly active in finding markets for mill refuse that would otherwise go to the burner. Approximate prices the primary manufacturers are obtaining for residual wood for various uses are shown in Table 3.

Loggers and primary manufacturers will be particularly happy to see an expanded wood fiber industry. Such an expansion will give them additional markets for residual wood and thereby let them better utilize their timber resources. From all indications the wood fiber industry need not worry about a raw material supply. If this industry is to be expanded, the main problems will be concerned with the development of markets and producing a product at a price that is competitive.

Discussion

C. M. Kreider (Elmendorf Research): As to the form "unit"—does it apply to both chips and sawdust?

Mr. Matson: Yes. It is used for both chips and sawdust.

M. M. Lehrbas (Southern Forest Experiment Station): Are you finding unit a satisfactory measure of selling waste?

Mr. Matson: Not too satisfactory but old measure held over to present day. The last 2½ years expansion necessitates some change. Suggest dry weight basis for buying or selling.

H. C. L. Miller (Miller Hofft): In a survey of small mills made in one Virginia County, we found a 70 year supply of suitable material left in the woods.

W. J. O'Neil (University of Missouri): 92,000 M Cord. What % could be economically utilized.

Mr. Matson: We realize most of this material is uneconomical under present day markets but it is a huge potential raw material supply. Also, most of it is fairly accessible. Washington made survey showing 76 percent of the logging residues were within 500 ft. of roads.

Mr. Johnston (Johnston–Crowder Mfg. Co.): What is included in logging waste?

Mr. Matson: All logs, chunks and tops down to 4" top.

James Bethel (North Carolina State): Table 1 shows S, greatest volume but say N. W. has best source.

Mr. Matson: Material is concentrated in west.

Ponderosa Pine Woodwork Residues for Dry Formed Particle Board

E. A. PATTON
Research Engineer, Curtis Companies Incorporated, Clinton, Iowa

Seven years ago, faced with a serious shortage of plywood panels for use in its doors and kitchen units, Curtis Companies Incorporated turned its attention to the daily accumulation of between 20 and 25 tons of woodwork residues resulting from operations at its Clinton, Iowa division, and asked of its Research Department the obvious question—"Can panels of good quality be economically made from this material?"

The answer to the question came more than two years later when a small production plant began to turn out sizeable quantities of a dry process particle board which is still being manufactured and successfully used in many items of Curtis Woodwork.

Board Properties and Uses

THE PARTICULAR DRY PROCESS particle board dealt with in this paper is a phenolic resin-bonded aggregate of Ponderosa Pine particles, ranging in size from those that will barely pass through a 12 mesh screen down to those that are ordinarily spoken of as "fines", or wood flour particles.

It is also characterized by a specific gravity of approximately 1.0 which, along with its smaller particle size, distinguishes it from the somewhat lower density, larger particle product now popularly referred to as Chipcore. The latter ordinarily is used for somewhat different purposes than the heavier particle board.

Since the purpose behind the development of "Prespine", as the Curtis board is called, was to furnish a panel with finishing characteristics at least equal to those of the plywood originally used in the woodwork items, it was necessary to manufacture the product practically free of surface voids. This was most effectively done by using relatively fine particles and pressing to relatively high density.

Other physical characteristics of the dry formed particle board are lightness of color, hardness, high tensile strength perpendicular to the surface, excellent screw holding properties, good abrasion resistance, low linear expansion, good bending strength, good weathering resistance, and good machinability. The board can be produced nearly as light colored as the average piece of Ponderosa Pine, depending, of course, upon the care taken in eliminating knots, bark and other dark-colored matter from the wood residue, and also in the selection of the resin. This light color characteristic enables the board to be used to advantage where natural or blond finishes are employed.

Its hardness, equivalent to that of dogwood, as determined by measuring the force required to imbed a steel ball of 0.444 inches diameter to a depth equal to its radius, together with its relatively high tensile strength perpendicular to the surface of 290 lbs. per square inch, make it an ideal core material for the single operation manufacturer of core-decorative laminate combinations.

Its excellent screw holding property, averaging 516 pounds for withdrawal of one-inch No. 10 wood screws imbedded ⅔ of an inch makes it desirable for use in furniture applications such as table tops.

Other uses and possible uses for the board include cabinet construction, drawer bottoms, door panels, flooring, bench tops, etc.

Raw Material

The raw material used in the manufacture of the particle board, which was formerly used entirely for boiler fuel, falls into two categories rather loosely defined as hogged residue and machining residue. This material is developed largely from shop lumber, and therefore the hogged residue contains a considerable quantity of knots, pitch pockets, bits of bark, etc. that were cut out in order to convert the shop lumber into clear cut-stock.

The hogged residue, containing the above-mentioned defects, is collected in a separate exhaust system, and is deposited in a separate bin. This material is largely in the form of chips from one to three inches long, and from ¼ to ¾ inches wide. The machining residue, on the other hand, is accumulated almost entirely from molders, stickers, sanders, boring machines and the like, which process clear lumber, and is therefore much "cleaner" than the hogged residue.

It is interesting to note that the hogged residue and machining residue each constitute approximately 20 percent of the total weight of lumber used, making the total residue approximately 40 percent. This is developed largely from No. 2 shop lumber.

The machining residue is preferred raw material in the manufacture of the particle board. It is available in practically the same volume as the hogged residue, each type amounting to approximately 10 tons per day, and since the particle board plant requirements are only five tons of residue a day, there is a more than adequate quantity of the cleaner machining residue available.

This does not mean that the hogged residue will not make a satisfactory board, but merely that it is second choice to the machining residue, due to the fact that it contains knot sections, bark, etc. which are undesirable in the event that light color is necessary in the finished panel. Also it occurs in coarser form and is, therefore, more difficult to grind to the required particle size than is the machining residue.

Since the particle board is fairly near the raw material source, a pneumatic conveyor system is used to con-

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vey the machining residue into a storage bin. It is fed from the bin as required by means of a conveyor chain over a set of magnets to remove tramp iron from the residue, and into a hammermill having a capacity of approximately 1500 pounds per hour. The residue falls from the hammermill as finely ground particles into another storage bin. It is drawn from the second storage bin by means of a screw conveyor as needed for eventual manufacture into panels.

The grinding rate of the hammermill is determined by the fineness of the material delivered to it, as well as by the fineness to which it is ground, and the 1500 pounds per hour figure is based on grinding machining residue or similar material. The same machine will grind less than 1000 pounds of hogged residue per hour because the hogged residue consists of larger chips, and therefore requires more reduction in size than does the machining residue.

Since all of the wood residue comes from kiln-dried lumber, the moisture content of the raw material is not excessive, and no drying operation is necessary. After passing through the hammermill, the wood has a moisture content between 6 and 8 percent, and it is in fact necessary to bring it up to 12 to 14 percent before pressing, in order to achieve proper bonding.

Mixing of the wood with water and phenolic resin is carried out in a muller-type mixer by the batch process. The resin content used is approximately 6½ percent, based on the air-dry weight of the wood. We prefer to use a one-stage phenolic resin to achieve lightness of color and good weather resistance, but other thermosetting resins are satisfactory for given purposes. Most two-stage phenolic resins impart approximately the same properties to the board as do the one-stage resins, with the exception of color, the two-stage resin producing a slightly darker board.

Panel Forming Process

The aggregate of moist wood residue and resin is loaded into aluminum trays by means of a specially-designed pan filling machine. These trays are placed in a five opening press loader which thrusts them into the press and at the same time pushes the five trays containing finished panels out of the press onto a stationary unloading rack. The press is then closed on the five newly-loaded trays and a pressure of approximately 325 psi. and a temperature of approximately 320° F. is applied for 4½ minutes. Following this, the pressure is slowly released in order to avoid blistering of the panels, and the cycle repeated.

These pressing conditions hold good only for the particular thickness and density of board that is described in this paper. Thicker boards require longer pressing times and have much more tendency to blister unless reduced in density.

The panels are air-cooled after removal from the trays and are then sprayed with enough moisture to bring them from a moisture content of approximately 2 percent to a moisture content of 6 to 7 percent after which they are flat piled to give the moisture a chance to distribute itself equally throughout the panel.

This is an essential procedure in case the panel is to be used for cabinet construction, door panels, etc., since the moisture increase from 2 percent to the average equilibrium moisture content of 6 to 7 percent results in a slight, but nevertheless significant, swelling both in thickness and in lateral dimensions.

The boards are then edge-trimmed on a double-end cutoff saw usually with carbide-tipped saws and are later cut to various sizes, some of which are sanded in drum sanders. The thickness of the panels is 9/32 of an inch plus or minus 1/64 of an inch upon removal from the press. Sanding brings them to a thickness of ¼ inch. Planing also has been used for thickness reduction where a somewhat rough, pitted surface is not objectionable as would be the case when the board is used for core.

One outstanding advantage of this type of particle board operation is the fact that it does not have to be large, and does not require a huge raw material supply for economical operation. Many woodworking plants could economically manufacture panels for their own use, and perhaps enjoy a limited outside market in addition. Our operation, which employs a 4- by 4-foot, five-opening, steam-heated press, consumes five tons of waste per 8-hour shift, and requires the services of 4 men plus a working supervisor per shift. Each shift turns out about 400 panels, or 6400 square feet of particle board. Since trimming and sanding is done in the main factory and not in the particle board plant, these operations are separate and require a small additional amount of labor. The labor involved in the manufacture of our board is higher than necessary, due to the fact that automatic equipment for handling the trays has never been installed. Also, the batch mixing process requires an operator who would not be required to operate continuous mixing apparatus.

Additional Residue Disposal

After removing approximately 5 tons of residue from the total daily accumulation, between 15 and 20 tons are still burned for fuel to supply steam and power for the entire factory, including the hardboard plant. In case it is desirable to operate the hardboard plant on a 2-shift basis, as has often been the case, an outside source of fuel can be used to supplement the reduced wood residue supply available for fuel.

Curtis hopes that someday its power plant boiler fires will be fed entirely by outside sources of fuel, and that all wood residues will eventually find their way into useful articles such as particle board or molded products.

Discussion

Mr. W. J. Tomford (James E. Stark Company, Memphis, Tenn.): Does speaker care to give selling price?

Mr. Patton: We do not sell the product except as a part of our manufactured woodwork articles.

James R. Roberts (Weyerhaeuser Timber Company): Do you make various densities?

Mr. Patton: No. We manufacture a board of specific gravity of approximately 1.0 only.

Jacob B. Huffman (University of Florida): What properties of resin binder for dry formed boards are desirable.

Mr. Patton: We have found the most desirable resin to be a one stage phenolic resin since it gives a light color to the finished panel, and has considerable flow properties coupled with fast cure.

N. M. Hicks (E. L. Bruce): Have you made tests on durability of inked grain?

Mr. Patton: Ink formulation is resistant to everything including paint and varnish remover.

Henry Beneke (Beneke Corporation): Can you supply material on screw holding properties?

Mr. Patton: Prespine has an average screw holding power of 516 pounds for withdrawal of one inch #10 wood screw embedded ⅔ of an inch.

Douglas Fir Slabs, Edgings and Bark—Wet Continuous Process Hardboard

W. J. RUNCKEL

Manager, Hardboard Division, Oregon Lumber Company, Dee, Oregon

Describes production of hardboard using green unbarked slabs, edgings and other chippable forms of material resulting from sawmill operation. Variety of species are used without selection or segregation, although preponderant source of material is Douglas fir. Bark constitutes over 25 percent of material used in process.

THE OREGON LUMBER COMPANY has been producing hardboard in its new plant at Dee, Oregon for over a year and is still operating with the same basic process with which it began. This process is considered unique in that all the bark normally occurring on solid sawmill residues is incorporated into the board. The bark, primarily Douglas fir, contains chemicals which impart desirable water resistance to the board without the addition of special chemicals for this purpose.

The product is marketed under the trade name Allwood and has been satisfactorily used in the automotive, furniture, railroad, display and advertising, and construction industries. The product is sold and distributed by the Simpson Logging Company of Seattle, Washington, who have exclusive sale of the product.

This plant was designed and engineered by the Blaw-Knox Construction Company of Pittsburgh, Pennsylvania, based on the Lighthall–Anderson patents which cover the utilization of the bark as well as the wood in conversion to a fiber product. The process represents a new phase in wood utilization using bark in high percentages for a useful and economic purpose. Earlier laboratory work presented before this Society has now been proved in actual production. The steps in processing used in this plant are available in a preceding paper for those wishing to review these steps, but at this point, I would like to comment on some of the points discussed in the earlier paper in terms of commercial production.

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Raw Material

Slabs and edgings are accepted from our present sawmill which cuts approximately 150,000 board feet per day. They are processed without further separation or preparation. The unbarked material is carried by conveyor off the slashers in the mill which cut the material to 4-foot lengths. These slabs and edgings are then conveyed by drag chain over a grated hog. Here, sawdust falls through. Thin or short blocks that might crosscut in the chipper are hogged and returned to our power plant for fuel. The slabs in turn are conveyed to the chipping plant where they are reduced to chip form. From this point on, the processing is typically that of a wet felting process using a continuous forming machine and a multiple-opening hot press.

The hardboard plant is now operating at 70% of the planned production of 80 tons/day. This has been due to lack of adequate warehousing and the gradual struggle of entering the market with a new product. The present waste material from the sawmill supplies both the power plant and the hardboard plant with raw material, steam, and power. The waste burner has become obsolete. The hardboard plant permits complete utilization of existing wood by-products with a minimum amount of processing.

Power is partly generated and partly purchased. At present, 500 kw is purchased from the public utility on a maximum 2000 kw contract. This 500 kw along with our present power output supplies the entire operation. As sales volume increases, and more steam is required with the addition of a new tempering plant, a greater proportion of power will be purchased. Defective logs, i.e., those having heart rot and shake which are now left in the woods, will be brought into the mill. The slabwood will be processed into hardboard with the remainder going to fuel.

The plant was also designed to accommodate another press line and thus double the production rate. When this time comes, slabwood will be purchased from the small mills in the area. It is also expected that a better job will be done on utilization of slashings in the woods area with portable chippers. The company owns an 18,000 acre tree farm on which utilization of thinnings will be practiced similar to that done in the Northeastern States. The use of unbarked wood simplifies this processing and indicates a worthwhile undertaking.

The raw material is made up of a number of species of timber, the preponderant source being Douglas Fir. The other species with reference to volume are: Western Hemlock, White Fir, Noble Fir, Western Red Cedar and White Pine. The percent composition varies, but no selection or segregation has been necessary. We have run as high as 50 percent of the minor species without affecting the physical properties of the product.

Chemicals

In all other commercial hardboard processes, certain percentages of sizing agents are added, such as rosin or waxes, to render the finished hardboard resistant to water absorption and subsequent swelling. We have not found any such additives necessary and yet our product shows excellent dimensional stability. We do, however, add ¾ of a percent phenolic resin in our Standard boards for additional strength and machining qualities.

(Continued on page 228)

Chipcore—Its Characteristics and Production

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President, Miller Hofft, Inc., Richmond, Virginia

Chipcore made from kiln dried leftovers in furniture operations is described and its properties discussed. Comparative test results on the material as produced from many wood types and sources are presented with a description of a representative Chipcore manufacing plant now under construction.

THE USE OF KILN-DRIED leftovers from furniture operations for the production of Chipcore is a specific example of wood utilization for composition products which is now receiving widespread attention. It seems inevitable that this should be the case because the conversion of block leftovers into a satisfactory core material to replace lumber core causes a substantial reduction in the total lumber cut required for a given furniture production. This also provides a saving in overall cost of that production and, in many cases, additional core material for sale at a profit. Many furniture operations develop kiln-dried block waste in quantities greatly exceeding that required for use as fuel, and disposal is often a serious problem. Converting such leftovers into a core material having a much higher value than fuel is a big step in improved utilization of timber resources. Unlike many conservation measures, it is one that is accomplished at a substantial profit to the owner or a corresponding reduction in his production costs. It is, therefore, of general interest to discuss Chipcore as a product, to present results of an extensive program of tests and experiments with the material, to indicate the control of physical characteristics and other properties which may be obtained by a complete and flexible manufacturing process, and finally to describe a plant now being built for a typical furniture manufacturer.

ABOUT THE AUTHOR: MILLER, H. C. L. Received BS degree in mechanical engineering from Massachusetts Institute of Technology, 1923. Author of numerous technical papers for ASME, TAPPI, FPRS and other groups. Formerly associated with Foster Wheeler Corporation, Proctor and Gamble Company, Goodyear Tire and Rubber Company, and with the U. S. Government during World War II. Member: ASMM, ASME, NAM and FPRS.

For purposes of this paper, Chipcore is defined as a relatively thick (⅜" to 1¼") panel produced by curing a suitably selected and prepared mixture of wood particles and binder under conditions of heat and pressure which will permit the polymerization of the binder and the formation of a stable mat having properties of strength, stability, surface and dimensions suitable for its intended use. The panels are usually formed flat but may be produced in curved or other shapes if desired. They may be made of uniform thickness throughout or corrugated, grooved, lined or dimpled by the use of suitable platens in the pressing operation. One of the most widely adopted uses of Chipcore is in the production of cross banded and veneered panels where it takes the place of edge-glued lumber core. It may also be used as sheathing and subflooring. Numerous other applications have been suggested and no doubt a more widespread understanding of the properties of this material will result in many other uses.

It cannot be over-emphasized that Chipcore is a particle board and not a sawdust product. The accepted particles used are graded to be as uniform in size and geometric shape as possible. Oversized particles are recycled in the chip preparation and fines are eliminated in order to reduce adhesive requirements and improve strength. Uniformity is important and it must be obvious that it cannot be obtained from masses of materials greatly differing either in size or shape. Many factors affect the characteristics and a full understanding of these is necessary so that the proper combination materials and processing equipment may be selected to produce the desired result.

To provide a basis for plant design and operation, an extensive experimental program has been undertaken. A large number of 38" x 38" test panels have been made from a variety of samples on a semi-commercial scale during the past 18 months. Poplar,

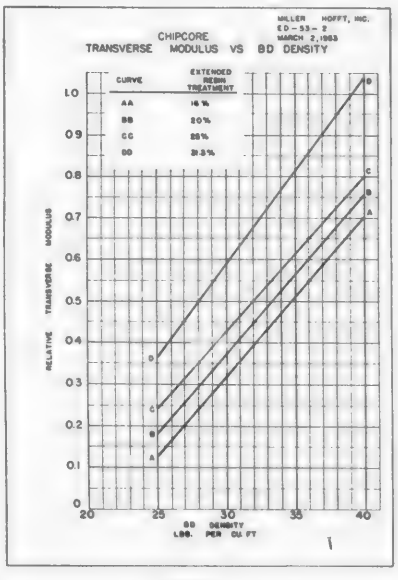


Figure 1.

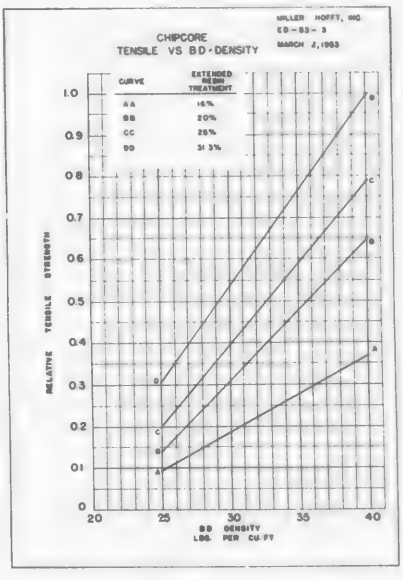


Figure 2.

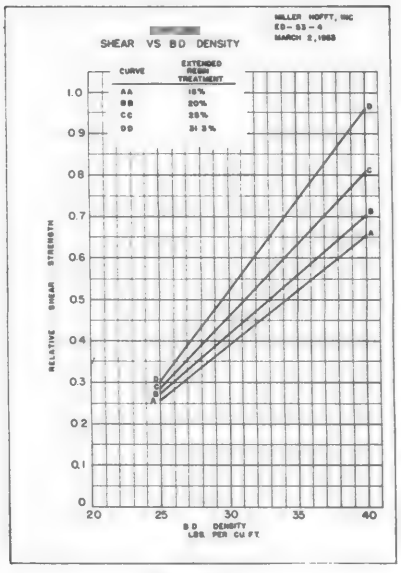


Figure 3.

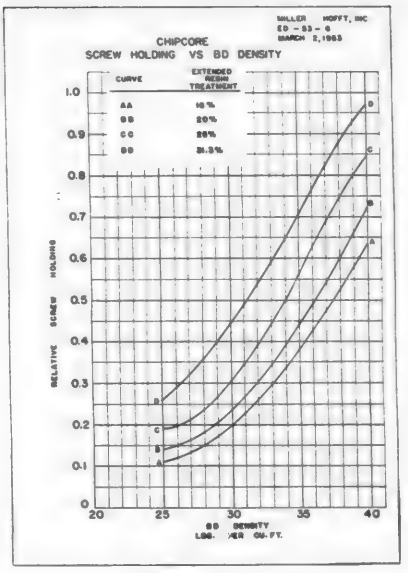


Figure 4.

gum, gum bark, oak, oak and southern pine, cedar, walnut, cherry, maple, douglas fir, and ponderosa pine have been used as raw material and the resulting panels tested for strength, stability, machining characteristics and suitability for various uses. One object of these investigations was to correlate the effect of binder treatment, density, species and chip shape with strength, dimensional stability and moisture absorption. A closely controlled series of tests were made on 43 sample panels made from the same wood (poplar) using the same system of grinding and screening but with varying density and binder treatment. All reported results are on samples taken from large panels and are the averages of many determinations. They are representative of what may be expected in full-scale commercial operation.

One conclusion from these investigations is that the type of wood used for Chipcore has no direct effect on the strength of the boards produced. It might have been expected that high strength material would give high strength board but this is not true. Chip orientation and shape, the density to which the mat is pressed, and the amount of extended resin treatment exert much stronger influences on board strength. For example, oak, which is hard and strong in solid form, splinters readily during grinding and produces a higher percentage of fines than do some of the softer woods. This seems to offset the strength advantage which might come from the oak itself. On the other hand, scrap veneer from softer wood grinds into long flat chips with few fines to give board of high strength with a modulus of rupture as much as 50% higher than that of board prepared from block wood of the same species. However, the density of the raw material itself does influence the dimensional stability of Chipcore because of its bearing on the net porosity of the panel.

As shown in Fig. 1, the transverse modulus—probably the most important strength test—is a function of panel density and resin treatment for any given wood. Density, however, affects bending strength much more than does resin treatment within the limits tested. This is also true of tensile strength, shear strength and screw holding power as shown on Fig. 2, 3 and 4. Hardness is a function of density only, being practically independent of resin treatment as shown on Fig. 5. All of these comparative tests were made on the same lot of poplar boards processed in exactly the same way except for the variations in density and resin treatment. While the results are reported in relative terms, they may be converted to absolute values by stating that the values for poplar Chipcore at 35 pounds per cubic foot bone dry and 20% treatment of extended liquid resin are:

Transverse Modulus	2260 p.s.
Tensile	780 p.s.i.
Shear	1670 p.s.i.
Screw Holding	196 lbs.
Hardness	1000 lbs.

Thus, on the basis of strength tests above, it is possible to make a Chipcore panels of nearly equal strength by increasing the density and decreasing the amount of resin. For example:

	A	B
Density, OD W/cu. ft.	35	36.3
% Resin Treatment	20	16
Transverse Modulus, p.s.i.	2260	2260
Tensile, p.s.i.	780	485
Shear, p.s.i.	1670	1670
Screw Holding, lbs.	196	194
Hardness, lbs.	1000	1130

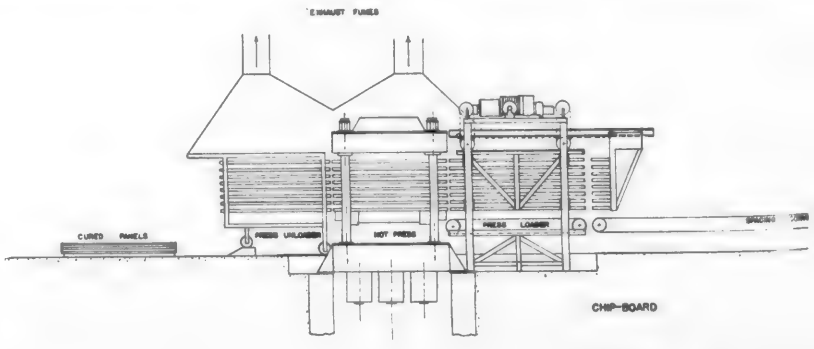
Tensile strength, which is most affected by resin treatment, is reduced by changing from A to B but other strength characteristics remain about equal.

As shown by Fig. 6, dimensional stability, the change of dimension with change in moisture content, is a function of panel density and resin treatment. Wood species has some effect on board properties in that it affects the net porosity of the panel at any given density, as well as the stability of the individual chips. The relative dimensional stability of Chipcore made from various woods, as determined by test, is listed below:

Walnut (least stable)
Maple
Poplar
Cherry
Oak and Pine Mixture
Cedar
Oak
Douglas Fir
Gum Bark (most stable)

At low resin treatment, dimensional stability is greatly affected by board density; at normal treatment (20%) it is moderately affected; at high treatment it is little affected.

The surface characteristics of Chipcore panels are important because they govern the amount of finish planing or sanding required prior to crossbanding and face veneering. Also, surface texture influences the possibility of "dimple" or "telegraphing" in



finished surfaces after extended service under varying conditions of temperature and relative humidity. Dimple effects are comparable to the appearance of glue lines in the finish veneer faces of lumber core panels. A number of comparative tests of the two constructions have been made which showed Chipcore to be at least as good as the lumber core in this respect even under extreme conditions. The lower the density, compatible with strength requirements, the less will be the chance of "dimple".

Thus, for each particular use a balance between density, resin treatment and chip size may be reached which will give adequate strength and acceptable surface properties with the minimum use of adhesive. We believe that too much emphasis can be placed on strength alone and that, for many applications, the most economical and generally satisfactory product is in the lower density range. The design, selection and arrangement of equipment must give due consideration to all influencing factors in each specific case and a plant provided which is flexible, controllable at each step, and easily adjustable to compensate for variations in raw material supply. Only with proper mechanical design and a knowledge of the effect of the several variables is it possible to achieve proper quality and uniformity of product.

A specific example of the utilization of kiln-dried leftovers in the production of Chipcore both for use in its own products and for others is the complete new Chipcore plant now under construction for the Cavalier Corporation, Chattanooga, Tennessee. This plant is expected to begin operation during the summer of 1953. The plant will substantially duplicate, in capacity and equipment, one which was put into commercial operation for the Wabash Screen Door Company of Minneapolis, Minnesota in the fall of 1952. However, the Cavalier plant will be more flexible in that it will be able to produce thicker boards.

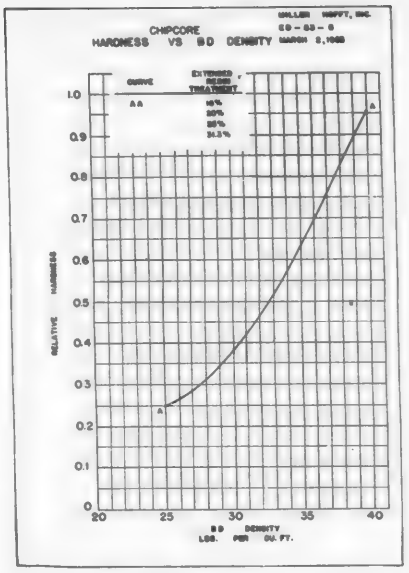


Figure 5.

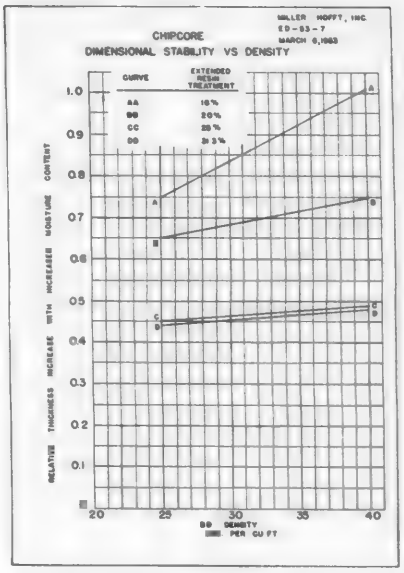

CHIPCORE
DIMENSIONAL STABILITY VS DENSITY
EXTENDED RESIN TREATMENT
RELATIVE THICKNESS INCREASE WITH INCREASED MOISTURE CONTENT
BD DENSITY LBS. PER CU FT

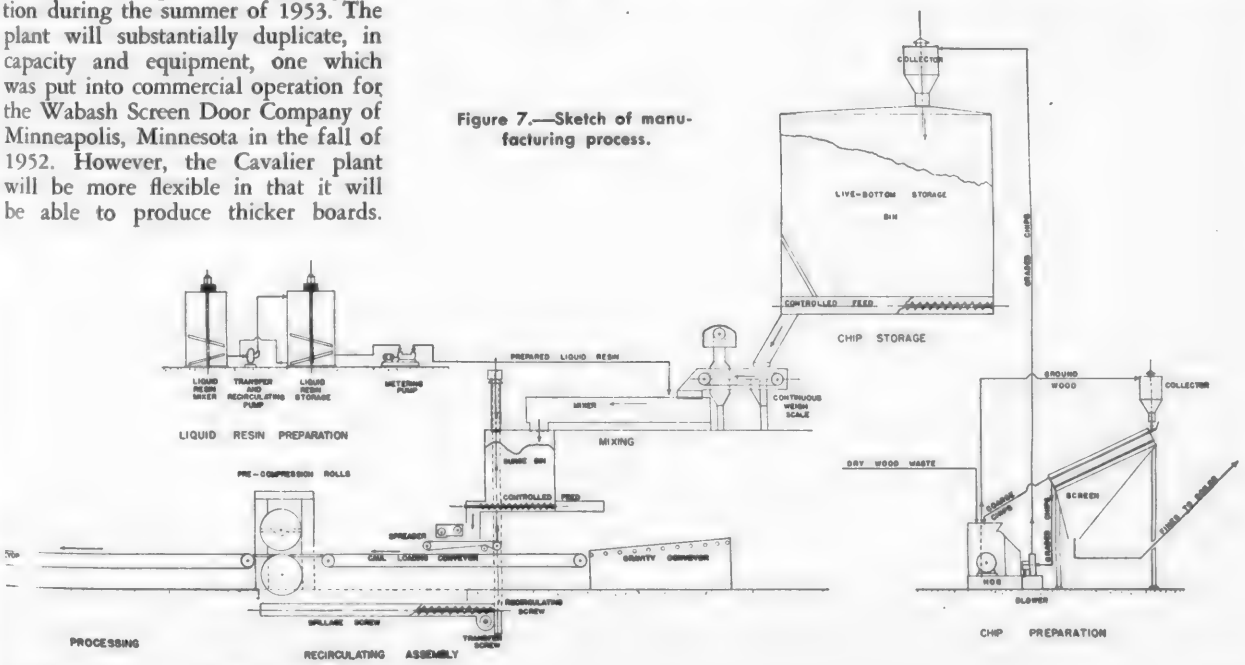
Figure 6.

Furthermore, it will incorporate improvements and design refinements which have evolved from experimental plant operations as well as the initial operations at Wabash.

The Cavalier plant now develops from 12 to 13 tons of block leftovers per day and these will furnish the raw material for the new Chipcore operation. This waste is kiln-dried and contains very little bark. It consists principally of eastern red cedar but includes a substantial proportion of poplar from the present lumbercore department. The proportion of poplar will be reduced when the Chipcore plant goes into operation because of the substitution of Chipcore for lumber core. All block leftovers from the manufacturing operations are delivered to a single conveyor which feeds a hog located in the present plant. This hog is a primary reduction unit. After passing through it, the leftovers will be conveyed through a blow pipe and cyclone system to an elevated live bottom storage bin which will be located above the treating floor in the new Chipcore plant.

Fig. 7 is a diagramatic sketch of the manufacturing process. The rough-hogged chips received from the main plant are delivered at the desired rate to a screen. Fines are sent to the boiler house for use as fuel; oversize chips are returned to a secondary grinder; the accepted chips are conveyed continuously to a weightometer. Extended

Figure 7.—Sketch of manufacturing process.



urea formaldehyde resin and accepted chips are then fed continuously, and at controlled rates, to a special mixer which discharges to a small surge bin having a controlled rate of discharge. The surge bin in turn feeds a special spreading and leveling unit which distributes a uniform mat of treated chips on metal cauls passing end to end under the distributor. This device is one of the most important elements in the whole process, its function being to lay down a level mat of thoroughly mixed and uniformly treated chips. The loaded cauls pass from the distributor through precompression rolls to a spacing conveyor which in turn charges the press-loading rack. The hot-plate press has eight 4-inch daylight openings and 54- by 100-inch platens. After closing the press to automatic stops and curing, the boards and cauls move on to an unloader. Here the boards and cauls are separated, the cauls returning along the conveyor line for reuse, and the cured slabs strip-stacked and conveyed to storage. Edge trim from the rough slabs will be returned to the secondary hog for regrinding and reuse.

All steps in the manufacturing operation are performed continuously except the actual pressing and curing of the panels. Appropriately arranged conveyors and storage bins give sufficient time for the batch loading, curing and unloading of the press. In the new Cavalier plant all motor drives for storage bin, metering conveyor, mixer, surge bin, loader and leveler, and recirculating arrangement for spillage and overfeed will be synchronized for control from a central point. The Chipcore manufacturing operation will be housed in a new two-story building. Storage is provided in the basement, the loading, leveling and pressing operations are on a single line on the main floor, while resin preparation, chip treatment, metering and mixing are on a gallery above this floor. The storage bin for rough hogged chips is still above that. Once the rough-ground chips are delivered to this storage bin, all material flows are thereafter under positive and variable speed control.

The capacity of the Chipcore plant will be 1000 square feet of ¾" board per hour. Sufficient leftovers in block form will be available for the production of all core material used in the plant's own production plus a quantity for outside sale. It is estimated that the incorporation of the Chipcore operation will ultimately reduce the lumber requirements of this plant by 2,000,000 board feet per year—a very substantial quantity—through the conversion of block leftovers, in excess of fuel requirements, to a core material for use and sale.

Discussion

W. J. Tomford (James E. Stark Company, Memphis, Tenn.): What is the primary hog and screen size used.

Mr. Miller: Acceptable chips are usually thin 6 and on 20 mesh.

Reavis Sproull (Herty Foundation): What about nailability? How far from edge can you nail?

Mr. Miller: We have no specific date. Would estimate about ½ from trimmed edge. Do have screwholding data from many tests.

R. P. Burton, Jr. (Bruce Company): Type of material has little to do with strength.

Mr. Miller: This refers to species. Our tests show that the determining factor in strength is the glue bonds rather than the inherent strength of chips themselves.

G. R. Twyman (Mississippi Products): What is moisture content of board out of press and should the panels be conditioned.

Mr. Miller: Yes. Strength increases with age or cure. Chips of 10% maximum dryness are used as raw material.

James R. Roberts (Weyerhaeuser Timber Company): What is temperature of cure?

Mr. Miller: About 300° F.

A. R. Tegge (Quartermasters Container Laboratories, Chicago, Ill.) What is significance of extended resin treatment.

Mr. Miller: 20% is 20 lbs. of extended resin per 100 lbs. chips. This is 7.6% urea solids per 100 pounds of furnished product.

M. M. Yan (?) (Abitibi Power & Paper Co.): Glue bond failure may be due to no solid glue line contact. If making same density of board is there any preference between hard wood and softwood chips.

Mr. Miller: Best is obtained surface with softer, more compressible chips such as from many hardwoods.

Mr. Roberts: How large an operation for economical operation?

Mr. Miller: We go to as low as 5 tons per 8-hour day. At five dollars per ton for waste, cost should be $75 per M. sq. ft. or less. (¾" panels.)

Richard L. Burkhart (Swain Industries): What is the variation in density across the face of the board and does this difference mean anything.

Mr. Miller: There will be wide and undesirable variations in density across the face of the board if effective and controllable automatic means are not employed to lay down a uniform mat of treated chips. We consider this one of the most important elements of a production plant and have developed special mechanisms for this uniform loading and leveling.

Analysis Technique for Hardboard Pilot Plants

K. W. GUENTHER

Forest Products Industrial Engineer, Coos Bay Lumber Company, Coos Bay, Oregon

Explanation is given for using statistical methods to determine characteristics of hardboards produced from various formulations and by alterations in the manufacturing process. Technique facilitates experimental analysis while making use of previously acquired data.

TO EVALUATE ACCURATELY the results of hardboard pilot plant experiments is often difficult. Coupled with this difficulty is the expense in time and money to carry on effective experiments. A technique that would facilitate experimental analysis, yet could utilize pertinent, previously acquired data would prove valuable. This paper introduces an analysis technique designed to serve this need. Since this method has proven applicable in one hardboard pilot plant operation, it may fill the needs of others.

There are primary phases of manufacture resulting in the production of pilot plant boards. The pilot plant developing the process, where this analysis technique was used, had the following as primary phases: (a) Cooking time and pressure of wood chips, (b) Type of attrition plates used to grind chips into fiber, (c) Type of wax added, (d) Amount of wax added, (e) Type of resin added, (f) Amount and dilution of resin added, (g) Moisture content of fibre, (h) Pressing pressure, (i) Pressing temperature, (j) Any special modification at any stage of the process. While other hardboard processes would have different primary phases, the principles involved are similar.

To perform a complete study of an experimental board, physical tests must be conducted. Most important of these are determination of: thickness, weight, specific gravity, flexural strength, water absorption, and swelling. The testing laboratory performs these routine tests and reports the results. The process and testing data are then recorded on a standard punch card for future reference. Punch cards, being a basic tool of this analysis technique, are described in the following paragraphs.

Punch cards come in a variety of sizes and combinations of holes on the edges. The card used in this application was 5″ x 8″, with a total of 94 holes on the edges. Figure I is a reproduction of this stock card. Data is recorded on the card by keying desired information into a system of a combination of hole numbers. In use, the cards are separated into cards having identical holes in a specific category punched and cards not having those holes punched. This separation is made by running a sorting needle through the holes in question and lifting the cards up. The cards with the holes punched will drop out; those cards remaining on the needle are not punched. Thus, data on all boards having a particular characteristic, or set of characteristics, may be readily compiled by study of the separated cards.

The holes on the periphery of the card are grouped by fours. Each four holes will record up to fifteen numbers when punched with a special hand punch; see Figure II. Using these fifteen numbers, data may be directly keyed, such as punch one equals 1 percent moisture content, punch two equals 2 percent moisture content. Grouping of data may be necessary because of a large number of values and a limited number of available holes. An example of grouping would be, punch one equals 1 percent to 5 percent moisture content, punch two equals 6 percent to 10 percent moisture content.

Another type of keying is non-direct. This is used where the data recorded

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FIGURE I: Stock Punch Card

FIGURE II: Recording of 15 Combinations in 4 Holes

FIGURE .II: Sample Pilot Plant Punch Card

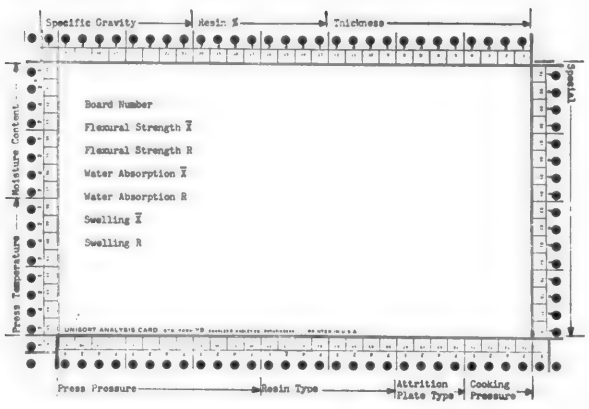
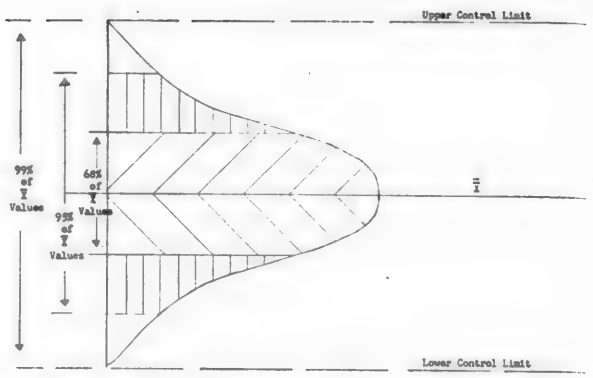


FIGURE IV: Sample Normal Distribution

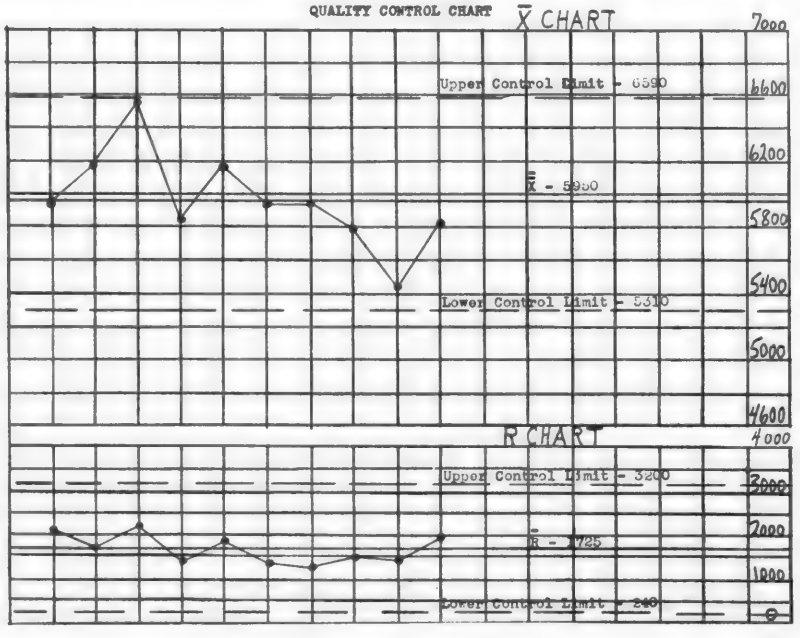


is not numerical, or is numerical but complex in nature. Examples would be, punch one equals resin A-62381, punch two equals resin A-37805. In addition to using one group of four holes for recording up to fifteen numbers, the group may represent one digit of a multiple digit number. Thus, to key thickness in thousands of an inch would require one group of four holes for the tenths digit, one group for the hundredths digit, and one group for the thousands digit. Punching the two holes in each of the three groups would refer to 0.222 thousands of an inch thickness.

There are six single holes located in three corners which may be used for simple keying. For example, punch one equals "condition X exists," no punch equals "condition X does not exist." Another advantage of the single holes is for giving an additional first digit in multiple digit numbers when the additional number would either be punched or not punched. An example of such use is specific gravity where the value would be 1.00, in which case the single hole would be punched to represent 1; or 0.99 where the single hole would not be punched in order to represent 0.

Because of shortage of punch-hole space, or a desire to see certain information in print, data may be written on the blank space of the card. For pilot plant boards it is of advantage to have manufacturing data recorded in the punch holes and physical test data written on the card. This permits a separation of boards by manufacturing data and subsequent study of written test results for quality control chart construction. Figure III is a reproduction of a pilot plant card ready for use.

Chart I: Control Limits, X̄, and R Values from Example A
Figures are in Flexural Strength p.s.i.



The punch card is an orderly, efficient method of recording data, whereas statistical quality control is an effective technique for analysis of the data. All the steps required to construct a quality control chart for pilot plant use will be given. This is done to enable an experimenter to install the system by the use of this paper alone. The following are examples of studies made through the use of punch cards and quality control.

A. Determination of the Expected Spread of Flexural Strength Values Under a Specific Set of Manufacturing Conditions. Punch cards from the file were sorted out that had the same conditions of manufacture and were of the same specific gravity class. At least ten boards (more than 25 are unnecessary) are required to construct a reliable quality control chart. From each card two values were copied. One value was the average or mean ($\bar{X}$) of the eight flexural strength test results obtained from each board. For best results there should be at least five test results on each board so as to get a representative average. The other value was the range (R) or spread between the highest and lowest strength results obtained in testing the board. The ten $\bar{X}$'s were averaged to give a grand average ($\bar{\bar{X}}$). The ten R's were averaged to give an average range ($\bar{R}$). The results of calculations may be found in Table I.

The next step involves computation of upper and lower control limits. These limits are the highest and lowest values of a board average or range that would be expected 99 percent of the time without a fundamental change in manufacturing conditions. Table II contains the formulas and factors for computation of control limits.

The computed control limits as well as the individual $\bar{X}$ values are plotted on Chart I. Had any $\bar{X}$ or R values

Table I—CALCULATIONS OF $\bar{\bar{X}}$ AND $\bar{R}$ FOR EXAMPLE A

Board Average Flexural Strength $\bar{X}$	Board Spread in Flexural Strength R
5920	2210
6190	1770
6500	2230
5820	1430
6170	1800
5930	1400
5940	1340
5790	1500
5420	1490
+5810	+2000
59,540/10 = Grand Average = 5950 = $\bar{\bar{X}}$	17,250/10 Average Range = 1725 = $\bar{R}$

fallen out of control, that board would have been eliminated from the group and the control limits been recomputed. This initial elimination is sometimes necessary to insure that the values used for the control limit calculation could all have feasibly come from the same parent population.

If a large number of boards (several hundred) had been plotted, the results would have been similar to Figure IV. A small number of boards (over ten) will approximately locate the upper and lower control limits which is close enough for practical purposes. This approximate normal distribution is the most common distribution found in nature. Although few if any phenomena exactly conform to its shape, the approximation thereof permits analysis. Awareness of this measure of a normal distribution as shown in Figure IV is of value in setting realistic specification limits. One can determine where the major portion of production will fall and adjust specifications to be realistic.

A study of Chart I indicates what grand averages and what variability can be expected from boards manufactured under these specific manufacturing conditions. Decisions as to the value of this class of boards can be made now. Should future boards of the same class being plotted on this chart fall out of control, it would be an indication that some unexpected change in manufacture had occurred. Investigation should take place to determine what manufacturing condition changed. Quality control charts show when something occurs that is unexpected, based on previously expected performance. In this respect quality control assists in dynamic production control.

B. **Comparison of Boards Manufactured Under Conditions as in Example A and Boards Having a Slight Variation from Those Manufacturing Conditions.** It was decided to investigate the value of increasing the dilution of resin added to the board by increasing the amount of water, but adding the same amount of resin solids. A series of boards was produced under these conditions, tested, and the information recorded on punch cards. The punch cards were sorted to find boards having the same manufacturing conditions and specific gravity class as the boards in Example A, but with the increased dilution of resin. The $\bar{X}$ and R values were then plotted on Chart II with the control limits from Chart I. A study of Chart II shows an increase in flexural strength due to the increased resin dilution. All the $\bar{X}$ values fall above $\bar{\bar{X}}$ as well as three out of control points above the upper control limit. This indicates a definite improvement in board strength. New control limits could be calculated for this new group of boards because of the promise shown by this experiment.

Other physical properties of pilot plant boards may be similarly analyzed by this technique, thereby giving reliable and systematic information on which to base decisions.

Table II—FORMULAS AND FACTORS FOR COMPUTATION OF CONTROL LIMITS

Number of Test Results per Board	Factor A_2	Factor D_3	Factor D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	.75	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78
11	.29	.26	1.74
12	.27	.28	1.72
13	.25	.31	1.69
14	.24	.33	1.67
15	.22	.35	1.652

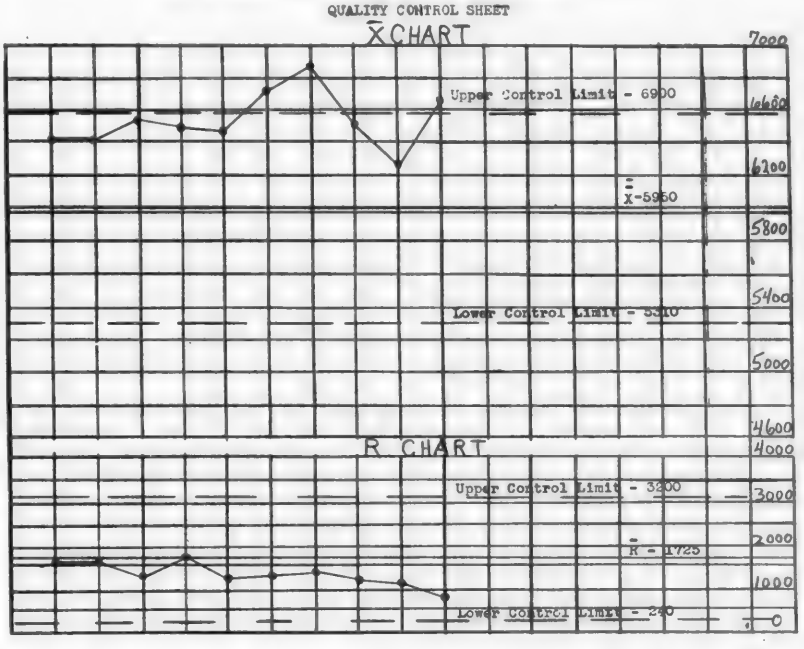
Upper Control Limit for $\bar{X} = UCL_{\bar{X}} = \bar{\bar{X}} + (\bar{R})\ (A_2) = 5950 + (1725)\ (37) = 6590$

Lower Control Limit for $\bar{X} = LCL_{\bar{X}} = \bar{\bar{X}} - (\bar{R})\ (A_2) = 5950 - (1725)\ (37) = 5310$

Upper Control Limit for $R = UCL_R = D_4\ \bar{R} = 1.86(1725) = 3200$

Lower Control Limit for $R = LCL_R = D_3\ \bar{R} = .14(1725) = 240$

Chart II: Control Limits from Example A; $\bar{X}$ and R Values from Example B. Figures are in Flexural Strength p.s.i.



Discussion

V. H. Clausen, Jr. (California Redwood Association): Do you have template to simplify punching of cards?

Mr. Guenther: The key is easily remembered or looked up, templates being of limited use.

Irving Isenberg (Institute of Paper Chemistry): How many factors can be sorted for simultaneously with hand sorting method?

Mr. Guenther: Best to sort one at a time. Have seen a false-bottom box with folding sides which permit inserting a number of sorting needles, hence sorting for several factors at once is possible.

M. M. Yan (Abitibi Power & Paper Company): Do you record routine tests each day? What do you do when card is used up?

Mr. Guenther: Recording is done as soon as possible, generally the same day.

TECHNICAL SESSION VII—Wed., June 17, 1953, 9:00 A.M.

Subject: Wood Machining and Equipment

Chairman: L. A. Patrousky

Recorder: Ralph K. Day

Designing Cutterheads for Maximum Production

C. C. CHEKOURAS

Manager, Cutterhead and Knife Department and Carbide Saw and Tool Department, Yates-American Machinery Co., Beloit, Wis.

In ordering a new cutterhead, the manufacturer should supply the designer with as complete information as possible, including cutting circle, best finish to be machined, horsepower requirements of the machine, the type of material to be cut, and other physical specifications of the machine.

Problems inherent in standardizing spindles and cutting circles, and how cutterhead design is affected by other machining factors, is also discussed.

BEFORE DISCUSSING the design of cutterheads, we should first review the machinery on which cutterheads are used. It has been said that a machine can do no better work than the cutterheads it uses. On the other hand, cutterheads cannot be expected to make up for a poor machine. Frequently, when a manufacturer is called upon to supply a set of cutterheads to machine an intricate pattern, further investigation shows that the cutterheads are to be used on a machine that is not qualified to do the work planned. During the war many small woodworking concerns, anxious to receive woodworking contracts, re-activated an old machine and then expected the products of the cutterhead and knife manufacturer to produce a product that would meet exacting government specifications.

When the designer requested information as to the condition of the machine for which he was to supply cutterheads, the owner usually reported that the machine had been doing fine work. This work may have been four-square work or a very simple pattern that did not require the exacting tolerances of the product he now proposed to make. As an example, one company had a machine doing fairly good work in four-squaring and making certain mouldings requiring only one cutterhead; but when they tried to manufacture tent poles, they found that end play, when using four spindles, did not permit production of a perfect octagon.

For the purpose of this paper it will be assumed that the machine itself is in reasonably good condition, and is equipped with enough power to do the work proposed.

Adequate power is an important feature in the design of modern cutting equipment. A West Coast mill at one time ordered a pair of cutterheads to work on the profile spindle of a matcher to split a 2 x 12 into three 2 x 4s. Although the cutterheads cut only a $\frac{5}{16}$ in. kerf, actual horsepower consumption tests showed that they consumed 14 HP when cutting at the feed rate expected. This meant that the lower profile spindle of the matcher had to be equipped with enough power to satisfactorily do this job.

It may seem strange that a machine supposedly having enough power to cut many of the West Coast paneling patterns would be inadequate for such a simple operation as splitting a 2 x 12 into three 2 x 4s, but observation showed these two cutters were revolving through a cutting arc large enough to split through 2 in. dimension stock. It is surprising how much power is required to perform an apparently easy operation.

The Correct Machine for the Job

Frequently, a mill temporarily substitutes a moulder for a matcher. Although it may appear to work in like manner a moulder should not be expected to do the work of a matcher. Although there are some examples of successful substitution of machinery, we can still be firm in saying that moulders and matchers are not interchangeable any more than are shapers and tenoners.

A few years ago, in following up a complaint regarding a small moulder, originally designed for furniture parts manufacture, an extreme case of misuse was encountered. The mill had been using this small moulder for the manufacture of 2 x 4s from fir at the rate of 280 ft. per minute! No wonder the machine was giving trouble! The most amazing thing was that it held together under such a strenuous burden.

Standardization of Spindles

Not too many years ago each woodworking machinery manufacturer had his own conception as to what should be standard spindle diameter. The cutterhead manufacturer, consequently, could not concentrate on engineering any particular sizes of cutterheads. First came standardization of sidehead spindles at $1\frac{3}{16}$ in. diamter. Today there are only a few special or small-sized machines on the market that do not meet this standard. Top and bottom spindles were standardized a short time later at $2\frac{1}{8}$ in. or $2\frac{3}{16}$ in. diameter. Further action is needed to accept one or the other as a final standard.

There is very little difference in strength between the $2\frac{1}{8}$ in. diameter and the $2\frac{3}{16}$ in. diameter, but machinery manufacturers anxious to serve their customers, will still provide a machine to fit whatever cutterheads a customer has in his tool room. Whenever a new cutterhead is designed for top or bottom spindle work, the cutterhead designer has to consider two different size spindles as standard. This creates a hardship in design and a tremendous burden in attempting to provide cutterheads for immediate shipment from stock. Most cutterheads can be re-equipped with sleeves or self-centering devices so that they can be reduced to $2\frac{1}{8}$ in. bore. It is thus evident that $2\frac{1}{8}$ in. diameter top

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and bottom spindles could become standard if machinery manufacturers were to insist upon it being standard, and if the machinery buyers would agree to make the slight changes in their present stock of cutterheads necessary to conform to such a standard.

Cutting Circle Diameters

Cutting circle diameters are also in need of standardization. Although the number of different cutting circle diameters has been reduced, machines are still being built today that require cutting circles of many different "non-standard" sizes, largely because the customer demands a machine that will use the cutters that he has on hand.

It would be difficult to discuss cutterheads that are not standard in size. The cutterhead manufacturer gives most of his attention to cutting circles of the more standard sizes. A designer recently was asked by his company to try to design a cutterhead that would carry eight milled-to-pattern bits in a cutting circle of 6½ in. diameter, one of the standards. It was possible to create a very sound and correct design for eight milled-to-pattern bits in a 7 in. cutting circle; but impossible to incorporate the same design in a 6½ in. cutting circle. Cutting circle limitations ruled out an otherwise good design.

There are many arguments as to whether a large or small cutting circle is more advantageous. The majority of fine work being done today is produced on machines operating with large cutting circles, not only because of the greater cutting arc, but primarily because the designer is able to design a better cutterhead when not subjected to the limitations of small size. Small size cutterheads necessarily mean narrower knives or shorter bits. This in turn means less life from the actual cutting tool, and results in higher upkeep costs for the cutterhead.

Safety Factor in Designing a Cutterhead

Although production is important, we must not overlook "Safety". Take the common, round cutterhead as an example. For many years, surfacing work was accomplished by a square head carrying four knives. At the turn of the century the round cutterhead became increasingly popular and today it has nearly replaced the square cutterhead in many applications. The design of a round cutterhead incorporates a cylindrical piece of steel that is slotted to receive a certain number of thin, high-speed steel knives. These knives must be held by some knife holding device or gib, which must be pushed up against the knife by some type of screw. If we were concerned only with four knives in a cutterhead of a standard diameter, we could use the maximum width of knife, the maximum safety factor, and produce an excellent design.

With stronger machines and more power, more feet per minute of material can be produced. It is obvious that the cutterhead must be equipped with enough knives to give an acceptable surface. Suppose that a machine is equipped with spindles turning at 3450 RPM and has a feed works capable of producing a 300 ft. per minute rate. In an effort to obtain acceptable material from this machine, a 10-knife cutterhead would produce a finish giving only 9.6 knife marks per inch.

Consider the cutterhead. As explained above, a round cutterhead would have to be designed and so machined that it would accept 10 knives. The sections of cutterhead body between the back of one knife and the front of the next gib slot would be very small. This design would definitely not be safe even if maximum production were obtained.

If the machine were requipped with a frequency changer or a variable speed spindle of some type, 4200 RPM could be used to produce nearly the same results with an 8-knife cutterhead, which in a 7 in. cutting circle, would be a good design. It might be well here to repeat the formula:

> "Knife marks per inch are equal to the revolutions per minute of the cutterhead times the number of knives divided by the feed rate in ft. per minute times 12."

The Right Cutterhead for the Job

Although there is no definite agreement on the correct cutting angles for the various species of work, it is an assumed fact that the harder woods require a lesser cutting angle, and the softer woods a greater cutting angle. Many times a manufacturer who has his mill equipped for softwoods, and his cutting equipment designed for such wood, will attempt to machine a quantity of hardwood on the same equipment, resulting in a very poor grade of work.

With straight knife work, he can back bevel his knives to reduce the cutting angle and get by. It is, however, quite difficult to increase the cutting angle to cut woods of a less dense species. This factor helped to make obsolete the square cutterhead, since it was so designed that the cutting angle formed by using a hand ground knife on a cutterhead was 40 degrees or greater—too great for either the hardwood or the softwood.

Round Cutterheads

Round cutterheads are nearly always used to machine flat surfaces. These cutterheads are designed from a 3 in. diameter cutting circle, having four high speed steel thin knives, to a cutting circle as high as 10 in. having as many as 16 knives. One head of this design has a straight bore and is held on the spindle by clamping collars or a set screw through the body of the cutterhead.

Another design is the journal type of cylinder as used in planers and matchers. These cutterheads range from cutting circles as low as 3 in. in diameter containing as many as 16 knives. The cylinder heads are all similarly constructed. Bearings are fitted to the journals to assure true running. The journal type head, as used in planing machines, is designed to hold the knife at a specified angle. The cutting angle is thereby fixed, and can be reduced only by back beveling the face of the knife.

The third type of round cutterhead is designed with a self-centering sleeve or self-centering device. This type can be taken off the spindles easily for interchanging with other type cutterheads. Demountable type cutterheads with various cutting angles can be used interchangeably on the same machine, thus making it possible to machine either hardwood or softwood.

Designing the Round Cutterhead

In designing a round cutterhead to fit the job, we should have before us such facts as the cutting circle required, the best finish to be machined, the horsepower qualifications of the machine, the type of material to be cut, and the other physical specifications of a machine. We first calculate the number of knives required for maximum production, always bearing in mind the safety factor. In many instances, the demands on a cutterhead are so great that it is necessary to review the qualifications and requirements with the customer. Required production may be obtained by increasing the spindle speed, using a rougher finish, or slowing down the feed rate. After the method has been agreed on, greatest possible knife width is calculated, since cutterheads are designed to use the maximum width knife. Usually the cutterhead manufacturer tries to design the knife holding gibs so that he may provide a stock of these parts. Since most cutterhead manufacturers are using a gib quite similar in design, this can be accomplished by having one large and one small size. In the past, the knife holding gib was not designed to provide for a wide variety of knives.

Milled to Pattern Bit Heads

A basic advancement in the design of cutterheads was the invention of a cutterhead using milled-to-pattern bits. Although improved design-wise, these cutterheads still embody the same features. The pattern is machined into the face bit, assuring maintenance of accurate pattern. The operator need only sharpen the face of the bits to continue the accurate pattern. These cutterheads for the most part can be categorized as follows:

1. Circular type bit head.
2. Dovetail type bit head.
3. Overclamp type bit head.
4. Vise-Grip type bit head.
5. Periphery milled type bit head.
6. Bolt-on type bit head.

Although the function of these milled-to-pattern bit cutterheads is nearly the same, there is a considerable difference in their design. The circular bit type head has been in use for many years. It is composed of a disc or discs that fit on a common hub and are bored to carry a series of circular tool steel bits. The pattern is machined into the periphery of these bits, which are aligned to operate in a common cutting circle, so that each does its share of cutting the pattern.

The dovetail type consists of a solid body of steel, either applied to a hub or including a hub. The body is so machined as to be fitted with milled bits having a serrated surface on the bottom. This surface will mesh with the surface on the periphery of the cutterhead. The bits are held in place by clamps applied on each side of the cutterhead. The clamps incorporate an angular jaw device that tends to grip the two sides of the bit and force it down firmly to the cutterhead periphery. There are various styles of clamps for this application, but in principle they are practically alike. Because of the necessary space required for the clamping devices, the number of bits that can be applied to a cutting circle is restricted. To add more knives in this cutting circle, the length of the bits would have to be reduced. In this type head, the designs vary from 4 milled-to-pattern bits in a 4 in. cutting circle, to 10 milled to pattern bits in an 8 in. cutting circle.

A common style of cutterhead known as the overclamp type, is practically the same as the dovetail type, except that the clamps are designed to clamp over the top of the entire bit rather than the portion of the bit known as the dovetail.

The vise grip type embodies the same features as the dovetail type, except that the bottom of the milled-to-pattern bit is not serrated, and the clamping members consist of two flanges machined to form angular clamps, one of them a part of the hub, and the other one a free flange. The loose flange is drawn to the solid flange by bolts. This is a very simple type of head and in many instances provides a very safe and sure operation. It is dangerous to use the vise-grip head if the dovetail slots have been damaged. The vise grip cutterhead is not laterally adjustable.

The periphery milled, sometimes called the L-Type, cutterhead is designed with a solid body with slots milled into the head body. One side of the slot is serrated. A bit, similar to the regular milled-to-pattern bit, has a protrusion which fits down into the slot. It is held by a series of set screws forcing the protrusion of the bit to mesh with the serrations.

The bolt-on type, which is similar to a square head, is provided with a milled-to-pattern bit, either drilled or slotted, so that a bolt can be utilized in clamping the bit down to the serrated surfaces of the cutterhead. Although it is sometimes possible to apply this type of bit to a square head, this is not practical, since the cutting angle must necessarily be quite minimum in order to apply this type of cutterhead.

Each of these cutterheads has desirable features. The choice of cutterhead should be guided by its actual application and reputation. Cutterheads can be designed for maximum production only after taking into consideration all the facts surrounding the job and the machine. Although production might be increased by having cutterheads with more knives or bits, safety must be considered. If more bits are used in the cutting circle of a machine, less life will be obtained from each bit. Many of the West Coast mills cut their patterns using round heads with many hand ground knives, principally to get the multiple knife work necessary to increase production.

Square Cutterhead

The square cutterhead is practical for small short run patterns but has proven itself impractical from the standpoint of versatility and safety. Maximum production must be gained from four knives when using a square head, since four knives are the most that can be applied. There have been a few cutterheads designed that have been known as a 6-wing square cutterhead, resembling a star in appearance. These have worked out successfully, but because of the design the width of the knife was too restricted to prove practical in its operation.

When Can We Use Tungsten Carbide Tipped Cutterheads?

Tungsten carbide tipping can provide an answer to many of our problems, including long wearing cutting edges. A few years ago it could be said that tungsten carbide was not practical in cutterheads because it could not be jointed, and it could not be applied to all patterns. At the present time it can be reported that tungsten carbide tipped cutters, both straight and with patterns, can be successfully jointed. All patterns have not been tried as yet, but the cutterhead designers are very pleased with the progress made thus far in the application of tungsten carbide tipped cutterheads. Cooperation between user and supplier is needed to speed up the application of tungsten carbide in cutterheads. When tungsten carbide is applied, the need of longer bits will be minimized and this in turn will permit more bits or knives in the cutting circle. This will mean higher production.

Cooperation between the users and the manufacturers of cutterheads and knives can definitely result in increased production and lower costs.

Discussion

S. R. Miller, Jr. (E. L. Bruce Company): How does rate of feed effect the work done by a sidehead, specifically with respect to torn grain caused by movement of stack?

Mr. Chekouras: The rate of feed is regulated to produce the finish desired. Suggest you refer to Patronsky's recent paper on "knife cutting problems" which includes several formulas on the problem. (Journal of FPRS—June 1953)

Mr. Miller: When using milled-to-pattern sidehead bits, it is impossible to change the cutting angle of those bits without changing the pattern, yet we have found that the cutting angle is wrong if we increase the feed rate appreciably. Since no change in the bits is desired because of a large inventory of the present ones, would increasing spindle spread help the same cutterhead and same bits to do better work at high feed rates?

Mr. Chekouras: Yes, increasing of spread would decrease size of chip.

W. J. Tomford (James E. Stark Company): Can you predetermine horsepower requirements for cutterhead operation or is it a trial and error method?

Mr. Chekouras: (Chekouras presented a formula here which the recorder was unable to follow)

Tungsten Carbide Can Increase Production

CLAUD E. DRAKE
President, Drake Corporation, St. Louis, Mo.

Paper describes proper application of tungsten carbide tools in the woodworking industry to increase production and profits per man hour of labor and per unit of machines.

HOW MANY ARE AWARE of what is going on in the light metals industry? Mr. Sterling Durst, in his paper presented in the Virginia Carolinas Section Meeting of the Forest Products Research Society, Roanoke, Virginia, November 3, 1950, spoke of the woodworking industry being inclined to scoff at the technical or scientific approach to any problem. If you could visit some of the new multimillion dollar plants that are now ready to spring into production on aluminum components and furniture and see the religious respect they have for technical and scientific analysis of production problems, the word research would take on a new meaning for you.

The object of this paper is to discuss the higher production rate made possible by the use of tungsten carbides. Such discussion should bring about a mutual understanding and a more equitable sharing of responsibility for development and progress in this field.

While this paper deals with higher arbor speeds in the utilization of tungsten carbides, it is recognized that there are abrasive types of materials where cutter arbor speeds have to be reduced to secure economic operation in terms of tool maintenance costs and elimination of excessive machine down time.

It is hoped that this paper will be accepted in the spirit of seeking highly efficient tooling under exacting production conditions. The industrial plant may be considered as a distinct entity where highly specialized engineering and attendant profit more than justify the endeavor. This is not meant as a criticism of that segment of the saw or tool industry that makes certain standard or stock models that are available off the shelf. They have their place and individual experiences are the best measure of their worth in the industrial plant.

Can you remember when all the woodworking trade journals were carrying advertising on carbide tipped saws that started off with the statement, "Jone's Carbide Saws will last fifty to a hundred times longer"? One of these advertisers sent me a circular letter with some hay in it telling me I should make some hay while the sun was shining, and set forth the profit to be made by selling their saws.

Where are all those fellows now—just two years later? Has the sun quit shining for some people? Did tungsten carbide fail? Did some people fail to recognize that in the full utilization of this new cutting agent, more was involved than the mere manufacture of a new kind of edge tool?

The essential requisites to a thoroughly satisfactory and economic tungsten carbide tool operation are these:

1. A thorough knowledge of the machinery on which they are used.
2. Familiarity with materials being cut or machined.
3. Ability to design and produce edge tools having proper engineering qualities for the job.
4. Proper application.
5. Proper operation.
6. Competent skilled maintenance of the tools.

Omission of any of these essentials in setting up a carbide tool operation is likely to result in failure.

Should some of these essential ingredients be furnished by the seller of the tool and some by the user of them? There is a definite responsibility to be assumed if success is to be achieved. As between the user and producer of the tool, which is more competent to assume the responsibility for careful analysis of an operation and engineering the setup? Can we escape the proposition that the product must bear all the cost of developing peak efficiency in machining operations? Is it realistic or practical to include the cost of all six of these essential ingredients, necessary for successful operation, in the sale price of edge tools? Does the user look to the supplier of the tools for engineering help in addition to furnishing the tool itself? Is the sun likely to keep shining for the fellow who fails to get enough of the profits from the operation to cover his cost plus a legitimate profit? Can the cost of the above six essential ingredients be included in the outright sales price of a saw or edge tool and the producer of the tools get enough orders to stay in business? Who does the user look to for help when the saw or cutter does not work right?

It is humbly submitted that it behooves the wood industry to protect itself by answering these questions.

We in the woodworking industry need the help that tungsten carbide can provide. We need it most for what it can do in terms of greater production for the man-hour of labor.

All this talk about carbide tools lasting fifty to a hundred times longer has lead us off into a detour. We have been blinded to carbide's real value. Even if tungsten carbide lasted only five or ten times longer than steel edged tools, it still has a quality that may be utilized to lower labor cost per unit of production to a point where there is no choice left as to its use. Whether it be sawing, planing, moulding or shaping, tungsten carbide will retain a cutting edge at

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tooth speeds and work feed rates that have only been dreamed of by the woodworking industry as a whole. This can be achieved without any sacrifice in quality or precision. To the contrary, far better quality and uniformity become the commonplace. Who would be concerned if carbide tools had to be changed once a week instead of once a month if the same production line, the same capital investment, the same man hours of labor would produce 25 or 50% more goods? Would the plant owner worry about whether the carbide tool would last fifty to a hundred times longer?

Specifically, what are the prime requirements to bring about this transition. Must all of our present machinery be junked? It does not. Many machinery manufacturers are not only willing but prepared to furnish their regular machines with higher speed saw and cutter arbors and higher feed rates. In many cases, they can furnish these new arbors and feed drives to modify your present machines. However, they do not take the initiative in this change as they feel the desire for it must originate with the user and for very good reason.

Can the machine tool builder bring about this improvement by himself? Can the edge tool manufacturer do it alone? Can the woodworking industry accomplish this development independently of the first two groups? Obviously, the very substantial reward inherent in this transition will accrue to the woodworking industry. Some of it will go to the machine builders, and some to the manufacturer of edge tools. Therefore, it is not illogical to reason that woodworking plants that have not locked their brain against progress and thrown away the key will be the ones not only to lead the way, but to reap the greater part of the reward.

We are on the threshold of a new era. One need only visit many of the new woodworking plants, in many cases not new as to the name, location, or roof, but new in thinking, new equipment, and new methods. Emulate these men and work with the machinery builder and allied suppliers of equipment.

Just what part of this program is still in the stage of engineer's dreams, and how much has been reduced to realistic, down-to-earth production practice? Starting right back at the circular or band mill, there is no sawing function today that, insofar as the fundamental mechanics of the operation are concerned, has not been duplicated using tungsten carbide as the cutting agent and working day in and day out on a production basis. Need we be naive any longer in our thinking about wide bandsaws or circular mill saws being offered for sale with tungsten carbide tips? It may be safely predicted that nothing will be accomplished on this until some substantial users of these products reach a point where they will be willing to stand up and be counted.

We have arrived at the point where circular and band milling of lumber can only continue to compete with new processes, where the whole lumber or tree is ground up, by going to tungsten carbide. With this change, far less lumber will be reduced to sawdust and the boards will require much less surface planing because of smoother cutting.

Will sawing machinery have to be junked to accomplish this? Some can be modified, some rebuilt, machines twenty to thirty years old junked.

Just what are the scientific and technical aspects of this transition that is already so far advanced? Have the fellows who made a few tungsten carbide saws and tools that failed to work brought things to a stop? Have the fellows who bought these tools and said they were no good put effective brakes on the enterprise? To the contrary, these experiences have highlighted the need for scientific and technical analysis of the problem and put us far ahead on the road to satisfactory economic solutions.

Excepting saw mill machinery, it is only about thirty years ago that woodworking machinery used cutting tool arbor speeds of 1800–2000 rpm. These speeds gave us saw rim velocities of 5–8000 fpm. It not only was considered unsafe to run these saws faster, but the steel available for saws in those days was prone to dull very rapidly at the higher speeds. We have used these many intervening years to develop arbor speeds that provide saw rim speeds up to 15,000–16,000 fpm. Now we must double that figure to enjoy fully the greater production and the profits that this new cutting agent, tungsten carbide, has to offer labor and management and the users of wood products.

Planer and moulder operations are all being done economically, and with far more satisfactory results, using tungsten carbide. Of course, in planers and moulders there are problems as to arbors, running balance, jointing and servicing the new tools. It is conceded that some of these problems are as near solution as those in the sawing operation.

The best brains in the edge tool industry are at work on the problems of planing and moulding with tungsten carbide tools. Every new idea, every experiment, opens up new horizons of thinking. Out of this movement is dawning new concepts of methods and tools that possess new values for the industry. If history repeats itself, and it always has, this enterprise in planing and moulding is due to be cracked wide open. We humans usually go about solving our problems by the most round-about, complicated processes that it is possible to conceive, then, suddenly, there appears the simple and obvious answer that we've been seeking. As of today, there are many indications that we are arriving.

The history of the carbide tipped circular saw is a parallel to this experience. Of all the problems that arose, many of them were entirely the result of traditional thinking, assuming that what had gone before was right. It happened that the revelation of the simple and obvious answer to a difficult problem the saw industry had to contend with—that of loose knots breaking teeth out of tipped saws—was revealed in a plant in Memphis.

Back in the winter of 1945–46, after finishing the development of a new type of grinder for the automatic grinding of circular saws tipped with tungsten carbide, the job of developing a set of standards for these new teeth presented itself. This led into a study of saw teeth. There were no books or records on the subject other than a few that dealt with filing and fitting various styles and patterns of teeth that were commonly known and used in the industry. Patent records disclosed some theory. Saw manufacturer's catalogs provided most information. Most of it seemed to be based on craft and tradition. If there is any scientific or technical work on the subject of the various tooth forms, why they are formed that way, and the reason for using a given number of teeth in a saw, it was impossible to find it. The whole proposition seems to have sprung from a cut, fit and try method until a combination was hit on that worked at a cost that could be tolerated.

However, there is another phase of wood machining where utter failure produced some deeper thinking. Outside the realm of circular saws in the planing and moulding operation it was found that such a wide variety of teeth and tooth forms would not work. To achieve acceptable results in planing and moulding, stricter limitations had to be observed. In planing and moulding, it was recognized that there was a highly pronounced relationship between cutter arbor speed, the number of cutting

edges or teeth used, and the feed rate, more commonly referred to as knife marks per inch. It was not possible to change any one factor appreciably without changing others, in order to retain or stay within certain narrow limits in terms of chip-loading.

There must have been those who had a deep-rooted suspicion that there was a close relationship between the mechanical laws that asserted themselves in planing and moulding, and those that might be applied to sawing. As a matter of fact, the very same law applies. If maximum performance is to be obtained from a saw of given specifications, running at a given speed, the chip-loading must be maintained within certain limits. If a saw speed and the number of teeth are constant, then there are only two other factors that will determine or vary the chip-loading. They are the rate of feed, and the thickness of the material being cut.

With reference to circular saw blades, the definition of chip-loading is: the thickness, width and length of the chip the tooth will cut with a given arbor speed, feed rate, tooth pitch and material specification.

Let us visualize a board being power fed through a rip saw at 300 fpm. Reducing this to inches per minute we have 3600 inches passing through the saw. The saw blade has 32 teeth and is running direct motor drive at 3600 rpm. If the saw is making 3600 turns per minute and the board is being fed at the rate of 3600 inches per minute, then there will be one inch of board travel to each turn of the saw. Obviously in one turn of the saw 32 teeth will pass through the cut, therefore, each tooth must cut a chip 1/32 inch thick. If a saw tooth is 1/8 inch wide then the chip will be 1/8 inch wide. If the board is 8/4, then the chip will be 2 by 1/8 by 1/32 inches, assuming the cutting action to be at a right angle to the plane of the board.

We must be mindful of one other factor. As the thickness of the lumber increases, more teeth are brought into working engagement. The power requirement increases, and the saw plate must be capable of supporting these additional teeth at work. Using this formula, we only need tables on minimum and maximum chip-loading to determine the correct specification for a saw to do a given job. Why have so many cutter head applications been changed to speeds of 7200, 10,000, and even up to 20 and 30,000 rpm? It is because good engineering does not permit cutterheads with excessive numbers of teeth. Higher feed rates have to be provided. These two factors would not yield to control chip loading properly. There was only one factor left that could be changed, the arbor speed. By increasing the arbor speed, factors one and two could be respected and chiploading brought under control.

Are sawing operations any less important than moulders, planers and shapers? Circular saws of given diameter and given gauges have definite limitations as to the stress they will work under. Assuming efficient tooth design, and sharp teeth, there are definite minimum and maximum chip-loading limits for each combination of saw plate thickness and diameter.

Operation of tungsten carbide tipped saws at 7200 rpm opens the way to the use of much thinner gauge saws at far higher feed rates with complete and proper engineering respect for maintaining correct chip-loading. Today, kerf removal and feed rates are important factors in material cost and man hours used per unit of production. The machine user's need for thinner saws and higher feed rates are no longer mere desire, they are imperative in terms of pure economics. Having determined through exhaustive tests what chip-loadings are well within tolerance for given diameters, gauges, and tooth pitches, it borders on an outright disservice to all concerned to accept orders for tungsten carbide tipped saws where the diameter, gauge, and number of teeth have been specified by someone who has very little or possibly no knowledge of saw engineering.

Now we can get at the heart of this problem of using tungsten carbide to get more production per man hour of labor, and per dollar of capital investment in equipment. We know that the size of the chip that the saw tooth or knife cuts is the basic starting point in working out the formula to achieve our objective. We know that we can not overload the tooth without getting into difficulty. We know that if we go to the other extreme—too light chiploading—failure looms. Therefore, the simple and obvious answer shines out like the sun:

1. For a given operation we know the size and kind of material we want to run.
2. We know the production rate required.
3. We use a saw or edge tool engineered with the right number and kind of teeth to do the job.
4. Then we run the saw or cutter arbor at the right speed to give us the chiploading we know is right.

With the last point we run headon into serious difficulty. Determining the right arbor speed is simple arithmetic. Obtaining the right arbor speed is something else. The machinery builders are trying to help us, but there are very serious problems in controlling or obtaining infinite arbor speeds. How can tungsten carbide help us out of this difficulty? It is an undeniable fact that tungsten carbide does hold the answer to this problem. Before we get into that, let us digress a moment to review our situation without tungsten carbide.

Thirty years ago the finest steel used in saws and cutters would lose its cutting edge so rapidly when operated at rim or cutting circle velocities much in excess of 8,000 fpm, that an arbor was seldom set up to run faster than a speed that would provide rim cutting speeds much in excess of 8000 fpm. Then we started getting alloy steel with tungsten and chrome and nickel, and arbor speeds that gave us cutting circle velocities up to 15–16,000 fpm. With these new steels, we found that cutting circle speeds above 16,000 fpm usually brought about a rate of dulling that couldn't be tolerated. That is where we found ourselves just a few years ago. Without tungsten carbide we had a limit of about 16,000 fpm cutting circle speed. We know beyond any doubt whatever, by actual production operations now going, that we can economically operate tungsten carbides at double these cutting speeds. Man hours used per unit of production were lowered in the past twenty years with high speed steel and raising arbor speeds from 1800 rpm to 3600 rpm.

How would you like to go back to 1800 rpm and carbon steel saws and cutters? How would you compete in today's market with such labor costs? How can tungsten carbide solve this arbor speed problem for us? Here is the answer.

We know that infinite arbor speed control holds such serious problems in engineering that there is no immediate practical solution. We know that through the use of frequency changers and improved arbor engineering, there is a thoroughly practical, down-to-earth avenue open to us to secure arbor speeds of 7200. We know that with this speed we can religiously respect good engineering principles and design saws and cutters with the right number of tungsten carbide teeth to retain complete control over chip-loading and provide higher production rate.

Are we going to take another twenty years to accept this transition? Did the woodworking industry have

light metals, plastics and other competition looking it squarely in the eye twenty to thirty years ago? Investigate any field of endeavor you will. Go back into history as far as the Bible will take you. See if you can dig up any real progress that ever took place without the enterprise having to contend with objectors and problems. Who were the winners—who were the losers when the final battle was fought and the final decision made?

Yes, we are here for this meeting because we are in love with woodworking. We also want to win the money reward—but that is looked forward to and worked for as proof we have fought a good fight. We can be proud that we undertake this labor for the thrill and victory that accomplishment of the objective brings us. The new people in the new industry who predict that the woodworking industry is staggering about on its last legs have failed to recognize that in overcoming our inheritance as to tradition and craft, we are developing new stamina that will serve us well in that run down the stretch to the winner's circle.

Discussion

Carl Chekouras (Yates American): Will a saw designed and tensioned for 3600 RPM work properly at increased speeds?

Mr. Drake: Yes. Saw will have to be opened up. (Here Drake refers to several applicable formulas several of which are apparently in Patronsky's paper previously referred to. The recorder could not get these down.)

L. A. Patronsky (Wabash Screen Door Company): Claud, isn't there some confusion between quality of cut and efficiency? That is, do you mean greater efficiency of material removed or better surface at chip load of 0.15 than at 0.30?

Mr. Drake: A saw traveling at high speed will do a better job due to centrifugal force, that is, there is less problem of saw stability.

Mr. Patronsky: As tooth speed increases, the material becomes the cutting agent. Theoretically, you could get the saw operating so fast as to dull almost immediately.

Mr. Drake: Yes. As speed of saw goes up you get a slight lowering of life between sharpening but you will get twenty to forty times the life of ordinary saws.

E. S. Johnson (North Carolina State): Can tungsten carbide tipped blades be used to gang rip rough lumber?

Mr. Drake: Yes.

Mr. Johnson: Please explain how higher arbor speeds will facilitate such use.

Mr. Drake: We have any number of such gang rip operations. Write manufacturers for the names of these companies. We hope to push this idea since we believe high arbor speeds will answer many difficulties such as enabling the sawyer to protect against flutter due to the heavy chips required. Gang sawing presents a serious problem since cutting takes place on top of plane. In a gang of saws the tendency of the board to climb causes teeth to grab and in doing so they take a terrific beating especially in size of chip. The remedy appears to be high arbor speed, proper hold down facilities and good bearings on both sides of arbor.

K. V. White (Greenlee Brothers): Can the same results, that is high run speeds, be obtained by increasing number of teeth and increasing diameter of saw?

Mr. Drake: No. Saw would have to operate under greater stress. Policy is to go to smallest saw possible.

T. C. Weill (Carboloy): Are tables available that show chip load ranges for various diameter of saws? Will they be published.

Mr. Drake: Yes. But not recorded and published.

J. E. Gayvitch (Gayvitch Lumber Company): High original cost and necessity of out-plant maintenance are major problems in use of tungsten carbide tipped saws. Recently, I understand, new alloys are being introduced which will permit sharpening at plant but still give good performance. Will you give us some information on these new alloys?

Mr. Drake: There are several cast alloys which have been tried, but what good reason would justify accepting something only half as good as tungsten carbide? You still will need some type of sharpening equipment.

Mr. Gayvitch: Professor Patronsky, the information available to me indicates that these alloys are not halfway measures as stated by Mr. Drake but have substantial merit in their own right. Would it therefore be in order to request the Machining Committee in the best interest of FPRS and the industry to have a paper prepared for the 1954 annual meeting covering the entire field of alloys available to the wood industries, their properties and their performance?

Norman C. Bye (Henry Disston & Sons, Inc.): Mention has been made of the necessity of stability in the rim of a circular saw and this stability is dependent on rotational stresses and work load. Rotational stresses and the size of blade to withstand them can be determined by calculation by the work load and abuse factors still have to be provided for by practical experience. Higher speeds, while desirable from a cutting standpoint, aggravate these design factors. Even after the saw blade design requirements have been met, the machines on which they run must have adequate power and rigidity, if good performance is to be obtained.

Mr. Drake: Consult with experienced operators. There are lots of variables to be considered, such as type of material, thickness, etc.

Norman Bye (Henry Disston & Sons): On observations made during trip to Canada. Disston has made several saws wherein the blade had been cut into three or four pieces and attached to arbor with promising results.

Summary of the Use of Tungsten Carbide Tipped Woodworking Tools in Regular Production

STEVEN P. KOCZAN

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This paper summarizes the progress made in the application of carbide tipped woodworking tools to production machining at The Singer Manufacturing Company, South Bend, Indiana. A description of the various applications of these tools along with the tool specifications found to be satisfactory are presented in this paper.

The development of cutting tools at this plant is continuing and the data were taken from the most recent records available at the time this paper was prepared.

ALMOST EVERYONE directly concerned with production machining and the related cutting tools is familiar with the nature of tungsten carbide. The fact that this product of powder metallurgy has a very great ability to resist wear is now widespread knowledge in the woodworking industry. The increased interest in carbide woodworking tools is apparent and numerous articles on the subject have been appearing in many of the leading woodworking magazines.

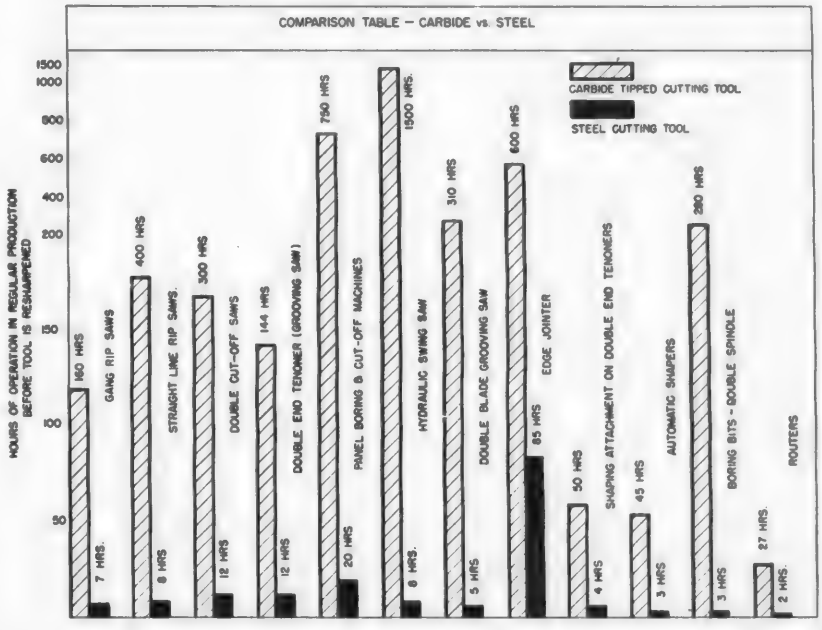
Various degrees of success with carbide tipped woodworking tools have been obtained and considerable testing has been conducted at this Singer Plant in an attempt to determine not only the performance characteristics, but to determine the correct application of the particular carbide tipped tools.

The actual experiments have been conducted in close collaboration with manufacturers of carbide tipped woodworking tools. This cooperation has resulted in the development of several carbide tools that have out-produced conventional steel in the quantity of parts machined before resharpening as well as the quality of the parts being machined. An analysis was made of each production machine before it was equipped with carbide tools, with consideration given to the condition of the equipment, the speed at which it could be operated, and the type of cutting operation to be performed. From this information and from performance records that were compiled while the cutting tools were in use, definite facts, pertaining to the types of cutting tools and their application, were established. This also enabled a comparison to be obtained between the regular steel cutting tools and the carbide tipped tools.

One reason for working in close contact with the carbide tool manufacturers was to permit a degree of control over the fabrication and grinding methods, thus insuring consistently ground shapes on the cutting tools. Another reason was to encourage the manufacturers to produce tools of a quality consistent with the requirements of each application. The cooperation between this Singer Plant and the manufacturers of the cutting tools has enabled minor changes to be made in cutting angles and tool design, which resulted in developing the most satisfactory tool for each application; also, carbide failure caused by improper brazing has been reduced and is now considered an uncommon occurrence.

Resharpening of Carbide Tipped Tools

At the present time our carbide tipped tools are returned to the manufacturer for resharpening. In most instances we have at least two identical sets of tools and a controlled sharpening schedule has been established to insure continuous operation without resorting to the use of the regular steel while awaiting a resharpened



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tool. Approximately ten days are required from the time a cutting tool is removed for resharpening until the time it is returned. The most undesirable feature about this method is the ten day time lapse and the handling involved in order to enable a tool to be resharpened. This handling increases the possibility of damaging the carbide, which reduces and at times cancels the saving produced by these tools.

An investigation to determine the feasibility of purchasing a precision grinding machine and the necessary diamond wheels for the purpose of providing sharpening facilities within the plant has been completed. This investigation revealed that, at the end of a fifteen month period, the cost of returning our carbide tipped tools to the manufacturer for resharpening equalled the initial cost of a precision grinding machine.

This cost was computed from the following information:

1. Number of times the tool required sharpening during the given period of time.
2. Cost to resharpen the tool when returned to the manufacturer.
3. Cost of packaging, postage and insurance required to return the tools for resharpening.

With the thought in mind of utilizing the idle time of the men in the saw filing room, which has been increasing as our plant has been expanding the use of carbide tools, an order was placed for a precision grinding machine. Also, a plan has been instituted involving the operation of a centralized control program covering the carbide tools within the plant. It is the feeling at this plant that a system of control will eliminate the overrunning of the tools and that a control program could be operated easily by the grinding machine operator who could maintain records of the running time of the various tools.

Carbide Tools Used in Regular Production

In order to summarize the use of carbide tools in more exact terms, the actual applications of the various tools at this plant are described in the following paragraphs.

First to be considered are the hydraulic swing saws which are equipped with 18 in. diameter, 100 tooth, alternate tooth bevel saws. These saws are operated for 1500 production hours before being removed for sharpening and, as indicated on the accompanying data sheet, produced a sizeable saving when compared to the 11 production hours obtained from regular carbon steel saws. The hours of production are based on a rough line capacity of 60,000 board feet per week.

The second group of cutting tools to be considered are those used for straight line ripping. For these machines 12 in. and 14 in. diameter, full face, 30 tooth rip saws are used, depending on the thickness of material to be ripped. One of the main interests in these machines is to obtain a satisfactory glue joint edge. Here it was discovered that we could rip a glue joint edge with carbide tipped saws of a quality consistent with requirements of our core stock providing that each tooth was ground to a near identical width. The kerf cut by these carbide tipped saws is between .155 in. and .159 in., compared to approximately .130 in. on jointed regular steel saws. The principal operation performed on our straight line rip saws is to rip core stock required for use in regular production. It is at this point that the defects are ripped out and this is done in a manner that will place the kerf loss in the removed section. This kerf loss is minimized by the saving resulting from the increased cycle life of the carbide saw.

Table 1—PRODUCTION MACHINES EQUIPPED WITH CARBIDE TIPPED CUTTING TOOLS AT THE SINGER MANUFACTURING CO., SOUTH BEND, INDIANA

Machine	Speed of rotation and feed	Operation performed	Description of carbide cutting tool	Ratio of cost to resharpen tool		Ratio of sharpening cost per 1000 hours of operation		Ratio of the total cost to remove tool for resharpening per 1000 hours of operation		Ratio of initial cost	
				Steel	Carbide	Steel	Carbide	Steel	Carbide	Steel	Carbide
Gang Rip Machines	3515 r.p.m. 60 ft./min.	Gang rip operations—leg squares, end and side bands. Oak, Walnut, Mahogany, Maple, etc.	12" Dia. Saw x 24 teeth, FFT-Kerf .130" to .135"	1	14.6	1.6	1	22.8	1	1	14
Straight Line Rip Machines	3500 r.p.m. 120 ft./min.	Ripping operations, removing defects in preparation for core building machine.	12" and 14" Dia. x 30 teeth, FFT-Kerf .157"	1	14.6	3.4	1	49	1	1	8
Double End Cut-Off Machine	3600 r.p.m. 25 ft./min.	Cutting-off leg squares in preparation for the turning operation.	12" Dia. Saw x 80 teeth ATB.	1	20.8	1.2	1	25	1	1	25
Double End Tenoners	3450 r.p.m. 25 ft./min.	Grooving and cutting-off veneered panels.	Cut-off Saw 12" Dia. x 100 teeth ATB, Grooving Saw 8", 10" and 12" Dia. x 30 teeth ATB.	1 1	15.4 ----	2.9 .8	1 1	11.5 10.7	1 1	1 1	23 12
Panel Boring and Cut-Off Machines	3450 r.p.m. 15 ft./min.	Cut-off operation combined with a boring operation on veneered panels.	16" Dia. Saw x 100 teeth ATB.	1	18.5	2	1	39.3	1	1	11
Hydraulic Swing Saw	3460 r.p.m. Power Feed	Swing Saw operations on the Rough Dimension Line.	18" Dia. Saw on 100 teeth ATB.	1	17.2	10.9	1	187	1	1	12
Double Blade Grooving Machine	3800 r.p.m. Hand Feed	Groove cut in a finished panel.	7½" Dia. x 8 teeth, Formed tooth groover.	1	6.4	5.1	1	36	1	1	7
Edge Jointer (experimental)	3500 r.p.m. 103 ft./min.	Jointing Oak, Poplar and Basswood in preparation for core building machine.	Shear tooth six cutter head, 6" long.	1	5.0	1.3	1	7	1	1	21
Shaping Attachment on Double End Tenoner	7200 r.p.m. 25 ft./min.	Shaping veneered panels.	Twin wing and Three wing cutter head, straight cutting edge.	1	10.6	1.2	1	12.5	1	1	8.7
Automatic Shaper	7200 r.p.m.	Shaping mouldings on veneered panels.	Formed shaper knives used with regular collars.	1	10.6	1	1.2	15	1	1	4.1
Double Spindle Boring Machine	3800 r.p.m. Slow feed with rapid traverse	Boring a seat for a hinge in a finished table.	Boring bit with two tracer 1.135" Dia.	1	18.4	5.1	1	97	1	1	2.3
Router	10,000 r.p.m. Hand Feed	Routing Masonite and Formica panels.	½" and 1½" Dia. Double Flute straight router bit.	1	3.8	4.8	1	17.9	1	1	.4

Third to be considered are gang rip saws. Satisfactory results with carbide tipped rip saws were obtained previous to the installation of a new rough dimension line; therefore, when two new gang rip machines were placed into operation they were equipped with 12 in. diameter, 24 full face tooth, rip saws. The question of kerf loss was considered and it was discovered that the kerf could be reduced from .145 in.–.150 in to .130 in.–.135 in. without shortening the useful life of the carbide tipped saw. These saws with the reduced kerf will operate 160 hours before resharpening is required, and the saving involved in this running time considerably more than compensates for their cost when compared to the shorter running time and kerf loss of approximately .150 in. that results from the use of regular steel saws. This conclusion is not considered a general statement and applies only to the saws and types of parts that are gang ripped as part of this rough dimension line.

A fourth group covers double cut-off and grooving saws used on the double end tenoners. Experimenting with these saws resulted in the development of carbide tipped grooving saws that are extremely efficient. For grooving operations, such as on veneered panels, case sides and rails, 30 tooth, alternate tooth bevel saws are used. These saws have been ground in a manner that permits them to produce a kerf width conforming with the required groove. Cut-off saws used on these machines and also on a double cut-off saw contain a larger number of teeth and are ground to an alternate tooth bevel. Basically, the shape of the carbide teeth is ground in a manner similar to regular steel saws, with full faced teeth used in ripping operations and an alternate tooth bevel used to sever the wood fibers for the cut-off operations.

Also, carbide tipped cut-off saws are used on our combination boring and cut-off machines. These saws are 16 in. in diameter and contain 100 teeth. Cabinet sides, backs and rails are bored and cut-off on these machines. Performance records compiled at these machines reveal that very satisfactory results have been obtained and a cost saving has been realized.

The fifth group consists of automatic shapers that are equipped with carbide tipped shaper knives. Several factors determine whether or not success can be obtained with these knives which are used primarily for shaping table and leaf cover mouldings. The same precautions apply that affect the operation of regular steel knives, in that each knife must be adjusted to remove an equal amount of material. Of course this adjustment is critical with either type of knife before maximum efficiency can be obtained from any set of shaper knives.

The production of Masonite and Formica tables has been greatly influenced by the use of double flute ½ in. and 1½ in. diameter carbide tipped router bits attached to a high speed router. The abrasive action of the binding material in these materials dulled regular high speed router bits within an hour, whereas the carbide tipped router bit averages twenty-seven hours in regular production before resharpening is required. Of course carbide tipped router bits are not superior to high speed steel for every application. The smaller diameter, steel shank, carbide tipped bits tend to fail more rapidly than the equivalent steel bit. The reason for this is that the cross section of steel in the carbide bit, that is available to resist torsionol and thrust loads, is considerably smaller than in the steel bit, and the result is that the smaller carbide tipped router bits tend to fail more rapidly under relatively small shock loads. Solid carbide bits have not been used in production to this date; however, it is intended to study the performance characteristics of these tools in the near future.

Other applications of carbides that are now beyond the experimental stage are machining operations that are performed on cabinet tables after they have been finished. Steel tools dulled very rapidly because of the abrasive qualities of both a thin layer of pumice that is on the tables at this stage of production and the finishing materials. Here, formed carbide tipped groovers that cut the hinge seats, full face carbide tipped groovers that cut the clearance for a hinge pin and carbide tipped boring bits that bore the seat for the sewing machine head hinge have been used to replace their steel counterparts. These tools were developed with the aid of several manufacturers of carbide tipped woodworking tools. These companies manufacture carbide tools for the woodworking and non-ferrous metals industries and this plant has benefited from the experience gained in their contacts with other woodworking plants. These special tools have been in operation for approximately the last two years and the results indicate that a large saving is involved.

Among the group of special tools are solid steel heads with carbide tips that are used on shaping attachments on the double end tenoners. The application of these two and three wing cutters has simplified the set-up operation of the machine in addition to producing a saving when compared to use of high speed steel knives for the same operations. These shaper heads are used extensively for machining veneered panels.

A bar graph illustrating the performance of carbide tipped tools at the Singer Plant in South Bend has been prepared and it accompanies this summary along with a table which lists some of the specifications of the tools now in use. The cutting tools listed in the summary are those that have been developed to a satisfactory degree, along with a comparison in the form of a cost ratio between steel and carbide.

Factors That Influence the Performance of Carbide Cutting Tools

From examinations of the carbide tools and the performance records at the various stages of development, some interesting observations have been made and are listed as follows:

1. Shaper knives must be fitted with one piece carbide tips. Two piece tips tend to chip at the point where they are joined. This chipping is more apparent when the shaping is performed on veneered panels where the glue lines multiply the tendency to chip the carbide.
2. The failure of a carbide tip to remain attached to the steel backing can be reduced to a negligible amount through proper brazing by the tool manufacturer befor the tool is released for use in production.
3. Improper handling of the carbide tipped tools by the set-up men can destroy any saving potential available in these tools by damaging the cutting edge and causing the carbide to break down and fail in operation.
4. In most applications, the feed speed must never be low enough to cause overheating of the saw. Very fine dust particles indicate a low feed rate; the other extreme is a very rapid feed which results in excessive vibrations. The correct feed lies between these two points and can be determined by actual experimentation.
5. Special applications require special tools which must be developed by trial, since general rules cannot be stated to cover all the applications of the carbide tools at the present time.
6. Carbide tools cannot be justified in every instance and at times, such as the use of small router bits that are subject to varying loads, are not as efficient as high speed steel.

7. Carbide tools must not be run beyond the point at which sharpening is required. When a tool becomes dull there is a tendency for the carbide to break down at a rapid rate. This statement applies particularly to power feed machines where a tool is sometimes run when it actually should be removed for resharpening. This statement is general and applies to steel cutting tools as well as carbide on power feed machines.
8. Partitioned storage racks in convenient locations will provide adequate protection for carbide tipped saws that are not in use.
9. The condition of the machine will greatly influence the performance of carbide tools. A machine having worn bearings or a machine subjected to vibration can be responsible for the failure of a carbide tool to perform satisfactorily. Of course a machine in poor condition will reflect in the performance of steel as well as carbide cutting tools.

Plan for Expanding the Use of Carbide Tipped Cutting Tools

This plant experimented with carbide tipped tools for production machining as early as 1937, although no satisfactory results were obtained from then up until 1949. It was only until the recent years that any degree of success was apparent and, as indicated by this summary, this success has resulted in the economical application of a large number of tools. A program of centralized control has contributed greatly to the proper application of the cutting tools described in this paper. It has been found that the full saving available from the use of carbide tools can be measured and obtained only through controlled application. The use of carbide at our plant has grown gradually and each tool, before being specified for a particular operation, was required to prove that it could be justified, with respect to economy and performance, within a 1000 hour production period. Carbide tools that did not meet these requirements were not considered acceptable. Our plan for the future is to expand the use of this relatively new woodworking tool, but only to the extent that the economy and performance of the tool meet the requirements that have been established by this plant.

Discussion

L. A. Patronsky (Wabash Screen Door Co.) Tool maintenance implies tooth replacement? Are you now or do you plan to do repair work as sharpening?

Mr. Koczan: No, we do not intend to do repair work; we plan to resharpen the carbide tools. Repair work will be done by outside suppliers of these tools.

Mr. _____ Has Singer made any comparisons of performance between steel and carbide tools with reference to chip load?

Mr. Koczan: We have made some comparisons. In this paper, however, emphasis has been on comparing the performance of standard machines fitted with steel tools versus standard machines fitted with carbide tools under actual production conditions with no change in the normal feed and operating speed of the machines.

Mr Patronsky: Table one on page two of Koczan's paper gives much information on efficiency of operation.

C. L. Blair (Mississippi Products Co.): You stated that you found a saving in Carbide Tipped power feed straight line rip saws. What is your chip load used in this operation on 4/4 stock?

Mr. Koczan: The chip loads of various machines were not listed in this paper. Tables on pages two and three do give the feed speed and the r.p.m. of our rip saw machines. The information listed in these tables may partially answer your question.

Mr. Patronsky: In your paper you refer to hours of production. Do you find that these vary according to the species of wood being machined?

Mr. Koczan: The performance of the tools listed in this paper did vary according to the species of wood being machined. An average running time, regardless of species, was listed in the paper, for the reason that the nature of our operation requires many species of wood to pass through the machining operation within a short period of time. Therefore the average running time was established to permit a running time cycle to be specified for a particular tool.

O. E. Smith (S. A. Wood Co.) What is industry's experience with gang ripping oak flooring at 250 feet per minute?

W. J. Tomford (W. B. Stark Co.): We have been successfully operating a gang rip at 120 feet per minute using higher arbor speeds to cut chip load on 1" stock.

Mr. Chekouras: Why did Singer start with solid heads?

Mr. Koczan: That was the basis of comparison. We had long been using solid heads.

Richard Erickson or *R. J. Nordby* (Onsrud Cutter Company): What success have you had in use of spiral cutterheads? We have settled for a sheer face on cutter which gives similar effect and works out satisfactorily.

Mr. Chekouras: We have been unable to find a machine to manufacture spiral cutterheads. A machine was traced and when finally discovered was completely dismantled and of no value whatsoever. Therefore, we do not manufacture spiral heads and stick to straight or sheer cutters.

Jack Hampton (Redco Tool Division, Red Lion Cabinet Company): Our company has since 1947 been producing a true spiral cutterhead with carbide knives centrifugally cast in an aluminum alloy body. Of course, the condition of the material such as moisture content, type of wood or material, and other general characteristics have a lot to do with the type cut received regardless of the design in the cutterhead. However, it has been found that under normal conditions in making straight cuts that tearout can be reduced approximately 90 per cent in moulder, jointers, tenoner, and shaper operations with true spiral cutters.

High Speed Production of Flooring

SYDNEY R. MILLER, JR.
Production Engineer, E. L. Bruce Co., Memphis, Tenn.

Brief description of an oak flooring operation is given, followed by an explanation of the difference between a normal flooring operation and a high speed operation. Paper outlines the parts played in a high speed operation of the raw material, the human element and the machinery itself. It concludes with a discussion of what high speed production can accomplish and points up the fact that patience and a good crew are a "must" in such a high speed plant.

Introduction

GREEN OAK MUST be air-dried for at least 90 days before it is suitable for kiln drying. Depending on the type of kiln and the time of year, kiln-drying will require 3 to 10 days. Next, there must be a period of at least 24 hours of "cooling" under a shed, after which the kiln-dried lumber is ripped into strips on a gang ripsaw, surfaced and run through a series of knot saws for removal of defects which are not permissible in hardwood flooring. After passing through the knot saws, the flooring strips are fed through a large machine known as a sidematcher which does everything except put the tongue and groove on the ends. A pair of special machines known as endmatchers perform this final operation. Then the flooring goes through the graders and to the bundling room where the strips are sorted into 167 different "pigeonholes" for color, grade and length. Finally, as each "pigeonhole" accumulates 12 pieces, a bundle of flooring is packaged. Having briefly reviewed the standard flooring operation, we can now study high speed methods.

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Definition of High Speed Production of Flooring

The majority of flooring plants run at 180 to 190 lineal feet per minute. This feed rate was established years ago by some of the larger flooring plants and has been maintained so steadfastly and so widely that it can be referred to as a "standard" operation. How much faster, then, is high speed operation? The fastest operation I ever saw was running about 340′ per minute and was averaging 18,000′ lineal per hour. In order to average 18,000 lineal feet per hour, the machine had to run at a feed rate equivalent to 20,000′ per hour so as to make up for the various items of "lost time" occasioned by gaps in the supply of material or "lap-ups" in the flooring machine itself. Our company has been experimenting with high speed, and the fastest that we have run was an average of 19,367′ per hour for two hours on some exceptionally good stock. However, it is our belief that such speeds are impossible with average lumber and so I am going to define a "high speed flooring operation" as one in which the lineal average maintained is somewhere between 15,000 and 16,000 feet per hour. My reason for saying this lies in the following fundamental fact about a high speed flooring operation. In most "standard" operations, approximately 90 percent of the knot sawing is done before the lumber is fed through the sidematcher, thus giving an assortment of short and long pieces which must be fed at the rate of about 45–50 per minute in order to keep the sidematcher running steadily. By contrast, only about 50 percent of the knot sawing can be done prior to feeding in a high speed operation, since it is physically impossible to keep a high speed machine running steadily on short pieces of lumber. Accordingly, in a high speed operation, a certain amount of the knot sawing is deliberately deferred. This means a certain amount of extra wood waste is put through the sidematcher in order to have longer lengths to feed. In the case of the ultra-fast operation mentioned earlier, only about 10 percent of the knot sawing was being done prior to feeding because that machine took the lumber so fast that you could not keep it running steadily unless you fed long flooring strips almost exactly as they came from the ripsaw. What such knot sawing and feeding practices will do to your waste is so fearful that it is the basis for our belief that a high speed operation should not be in excess of 15,000 to 16,000′ per hour. We believe that, at this speed, we are able to do sufficient knot sawing before the sidematcher to permit the feeder to get the utmost out of his lumber with respect to grade-yield and minimum waste. A faster speed than 16,000 ft. per hour, we have found, will inevitably result in wasteful feeding, excessive lap-ups in the machine and, usually, poor grading resulting from a fluctuating flow of material. A plant running very high-grade lumber might successfully run faster, but not plants running lumber which will be a mixture of No. 1 Common, No. 2 Common and 3A Common grades with a small percentage of a special grade of 3B Common. It is based on using such lumber that I restrict my speed to 15,000 to 16,000 ft. per hour. Now then, what production do you get from a high speed operation?

Production from a High Speed Unit

The story on production can, perhaps, best be told in tabular form as in Table 1.

Table 1

Average lineal feet per minute	Lineal average per hour	% Increase	Lineal run: 8 hours	Bd. ft. 2¼ in.: 8 hours	Bd. ft. per hour
180	10,800	------	86,400	18,750	2,344
233	14,000	29.6%	112,000	24,300	3,038
267	16,000	48.1%	128,000	27,800	3,475

Figures shown in column four are actual machine run. Columns one and two were obtained by working backwards from column four. Columns five and six are the yield figures corresponding to the machine run figures. But wait, let's take a little closer look at some of the factors involved.

Raw Material Versus High Speed Operation

There is a tendency on the part of those not directly engaged in the production of flooring to lose sight of the fact that we are not dealing with a predictable raw material. In steel, for example, man compounds the exact proportions of iron ore, carbon and associated materials so that, when the steel reaches the machine shop, it is a raw material whose properties and behavior can be exactly forecast under any given set of circumstances. A flooring plant, on the other hand, is dealing with a raw material grown in the forest and subject to such a wide variation in drying qualities, internal stresses, strength, hardness and a myriad other properties that you are safe in saying that no two boards are exactly alike. What this means in just one phase of operation was demonstrated during a test run made not long ago. Rough Oak lumber of about 26 percent moisture content was placed in a series of natural-draft kilns and was, ostensibly, dried to a moisture content of 5 percent. Then, while the stock was being run, 453 pieces were picked out and given an oven test to determine what moisture content they had actually reached as a result of the kiln drying. Because of the natural variations in every board, and because of the normal mixture of plain-sawn and quarter-sawn boards, there was a range of from 2 percent to 15 percent in moisture content. The lumber that was too dry constituted an added hazard in a high speed flooring operation in that it makes the lumber far more brittle than usual and gives rise to an excessive number of lap-ups and the possibility of torn grain in the face work. Most lumber above 5 percent is not a problem. Our company likes to ship the finished product at about 8 percent moisture content, which is nearly a median point in the moisture range of flooring. If the relative humidity in a location is 28 percent, flooring will stabilize at about 6½ percent moisture content, while at 72 percent relative humidity, the flooring will stabilize at 14 percent. However, lumber is handled so quickly in a high speed unit that, unless you have very close supervision, those occasional boards which come through at 10 percent to 15 percent can be through the machine and gone into flooring before you catch them.

A "standard" unit, with its slower speed, will not "lap-up" as badly on the over-dried lumber. The knot sawyers, because the unit is setting a slower pace, will usually catch and throw out those boards which are slightly heavy for proper use. Similar examples could be cited, but the problem comes down to the one fact that lumber is an extremely variable raw material. The faster it is handled, the more such variation offsets operation. This fact bears directly on the question of the human element in a high speed operation.

The Human Element in a High Speed Operation

Many people think of a high speed operation as one in which every man present is working at maximum physical speed and that such a plant overworks its men. To the contrary, in our operation, we literally "overwork" the sidematcher itself with a high feed rate, but we spread out the human work so that no man works harder than he would in a "standard" operation. Our reason for doing this is basic. The faster knot sawyers and feeders have to make decisions regarding the proper method of cutting the lumber and feeding it, the more it is necessary to supervise the operation and the more possibility there is for human error to creep in. Some idea of how this increased speed increases the number of pieces to be handled is shown in table 2.

Table 2

Av. lineal ft./min.	180	250	32[illegible]
Pcs./min. to feed sidematcher	45–55	46– 57	54 - 60
Pcs./min. to 1st endmatcher	65–70	80– 90	86–110
Pcs./min. to graders	70–80	80–100	115–120
Pcs./min. to rack punchers	53	68	84

Obviously, the faster the flooring machine is run, the more pieces per minute must be handled at each point. In some places, such as feeding the sidematcher, there simply isn't room to add men, and so it is important, as explained earlier, to keep down the number of pieces per minute that must be handled. In other locations, however, additions of machinery or different arrangements will permit the aggregate handling of more pieces per minute by distributing them among more men; so it follows that, every time you speed up a flooring operation, you must add men. To a certain extent, the number of men you must add can be held down by using a higher grade of lumber but there are obviously strict economic limitations in this direction. Therefore, it remains basically true that the balance between men working and the quality of the raw material itself constitutes one of the governing factors in the manufacture of flooring. To explain further, I recall very clearly a flooring plant in which we were scheduled to run 14,000 ft. lineal per hour. We attempted to do this using nothing but No. 2 Common, 3A Common and 3B lumber. The very best we were able to do with the men allowed was somewhere in the neighborhood of 12,000 lineal feet per hour. Then, one day, we slipped in a load of lumber containing about 20 percent of No. 1 Common. That flooring plant simply "changed its spots" while you looked at it. We were able to raise the speed to 14,000 ft. an hour immediately without adding a man or changing any machinery.

I once saw a flooring plant running at 180 ft. per minute and producing about 17,000 bd. ft. of flooring per day with exactly 17 men. The lumber was so perfect that it required only one knotsaw in the plant, which produced 67 to 75 percent of Select and Better flooring day in and day out. There was nothing unusual about this plant. The lumber was so perfect that there was little knotsawing to be done, with relatively few pieces to be handled all along the line. It was therefore possible to do the job with a small number of men. This operation points up the fact that it is a measure of the number of pieces to be handled that determines how fast you make flooring. To obtain a given production rate, it is necessary either to increase the number of men or to increase the grade of flooring lumber being used, and, since the lumber is not getting any better as the years pass, it is obvious that higher production rates are generally obtained only by adding men and machines.

Machinery Performance at High Production Rates

By and large, the electric flooring machines in use today are heavy enough to take the punishment involved in a high production rate. One of the most "punished" pieces of machinery in a flooring plant is the heavy gang ripsaw. When this machine was designed and built, the maximum amount of lumber ripped was between 2,000 and 3,500 bd. ft. per hour. Today, the machine handles 4,800 to 5,500 bd. ft. per hour, yet that saw stands up beautifully. The same thing can be said about the sidematcher and the endmatchers. Fundamentally, they are all rugged enough; however, there are some component parts that have needed improvement.

In our case, we have replaced almost all cast iron gears with steel, and we have developed a method of putting Sterlite (a very hard welding compound) on our bedplates, receiving bars, pressure bars and sidehead dogs. Also, we are presently experimenting with a means to put this same hard compound on our rollers in an effort to prolong their life. An example of the effectiveness of this program lies in the fact that we used to change bedplates on a high speed sidematcher about once a month, whereas the present Sterlited bedplate was installed 18 months ago and is still in good condition. Obviously, the using of steel gears and extra-hard surfaces reduces the amount of overtime maintenance required to keep the machine operating properly. However, it also has the extra advantage of insuring more reliable operation during each working day that the plant runs.

Speed Control

We have been installing variable-speed drives on our sidematchers. Through the use of such variable-speed drives, we can slow down the sidematcher if we hit a bunk of bad lumber and then speed it up when we hit a bunk of good lumber, yet we never lose a second of production time in making such changes. As a result, we are able to maintain a constant flow of pieces to the key men in our plant and, thus, are able to keep them operating at maximum productivity without overworking them at any time. Simple as this improvement sounds, we have found that it is one of the most useful tools in our flooring operations today, and we are presently engaged in supplying a majority of our units with such variable-speed drives.

Cutters and Knives

Our company ran a series of tests on knives and cutters in an effort to learn what might be expected from those we are currently using. We learned that the average run for a set of 10 in. flat knives used in the bottom cylinder of a "standard speed" sidematcher was about 38 hours. In the case of sidehead cutters, we tested 5 different makes and obtained runs that varied from 29 to 37 hours. What this amounts to is better shown with this set of figures. In 38 hours, the machine ran 410,400 lineal feet. With 10 knife marks to the inch and 8 knives in the cylinder, each knife made 6,156,000 cuts between grindings. However, as satisfactory as our present cutters and knives are, it would undoubtedly be an improvement to have some that would run even longer. Neither our cutterheads nor our thin knives will run a 40-hour week without changing. With cutterheads and knives that average 29 to 38 hours between grindings, there inevitably comes a time toward the end of the run when the work being done by that cutterhead becomes doubtful, yet the machine man attempts to stretch it out until quitting time in order to get a good run. Furthermore, with a freshly-ground set of sidehead cutters, the average machine man will often start off with a slightly oversized match of the tongue and groove because he knows that, when he joints one more time, the match will be just about right. Our company has experimented from time to time with carbide cutters and, so far, has found them unsuccessful because of our inability to joint them or to keep the carbide tips from breaking loose. However, I believe the day will come when such cutters will be perfected and entirely successful. Then the "down time" for jointing, opening or closing the match, or replacing dull knives will be reduced to the absolute minimum and the work done will be uniformly good.

However, every time I think about present-day costs of carbide, I wonder if they will ever be cheap enough to risk in a flooring operation. A short time ago, I was standing beside a flooring matcher when the set screw fell out of the pineapple infeed-roll and landed exactly crosswise between two flooring strips. That threaded set screw corrugated both the top and bottom knives as perfectly as you could ask. Knowing how brittle the brazing in carbide tools is, I shudder to think what might have happened to an expensive group of knives had they been in there at that time. Nor is that an isolated instance. We often run into nails, bullets, pieces of porcelain insulator and barbed wire, around which the tree has grown, but which are hidden to the eye until they go through the flooring machine. However, I am hopeful that it will not be too far off before carbide tools will do such a job without faltering. Recently, a metal light dome fell down into a large carbide-tooth saw we were running on a double end trimmer. The saw sliced through that fixture and kept right on going without losing a tooth nor impairing the work it was doing. Several years ago that would not have been true, and so I am very optimistic for the future. So much for the machinery phase of this high speed production of flooring.

What High Speed Production Accomplishes

After observing one plant operating at 14,000 ft. per hour and another at 16,000 ft. per hour, I have reached several conclusions. As mentioned earlier, there are many more "headaches" involved in getting adequate lumber ripped, holding down waste, coördinating the steady flow of materials, obtaining a good grading job and then getting it properly bundled and into the warehouse. That is inherent when any operation is speeded up appreciably. However, there seem to be some definite benefits. Each of the operations where we have increased speed is a single-unit plant. Prior to increasing the production rate, costs were as much as 30 percent higher than comparable costs at multiple-unit plants. Since the increase in production, costs are now comparable to and some times slightly lower than the multiple unit plants. True, a single-unit plant running at "standard speed" on high-grade lumber and with a minimum of personnel will show the lowest operating costs of all, but I am assuming that most flooring operations have to contend with lower and lower grades of lumber as the years go by, while only a very few plants are still privileged to have beautiful lumber in any great quantity. Therefore, if you can lower your costs to a figure that compares well with a multiple-unit plant, I think you have done something.

But there is still another factor. That is the added quantity you have to sell. Assuming you sell it all at the same margin of profit as before you increased production, it is obvious that you take care of your fixed overhead and have a chance to net more, simply because you have more footage on which to make a profit. An "intangible" is the morale of the crew. They seem to take pride in belonging to a

(Continued on page 228)

TECHNICAL SESSION VII—Wed., June 17, 1953, 2:00 P.M.

Subject: General

Chairman: R. M. Carter

Recorder: R. C. Musselwhite, Jr.

Effects of Treating Variables on Absorption and Distribution of Chemicals in Pine Posts Treated by Double Diffusion

R. H. BAECHLER

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The double-diffusion method of treating wood consists of soaking green wood in an aqueous solution of one chemical, then in an aqueous solution of another chemical. The two chemicals diffuse into the wood and react to form a precipitate that is toxic to fungi and termites. Favorable results were obtained with posts set in the soil for 11½ years in an area of high decay and termite hazard.

This report summarizes the results of studies of the absorption and distribution of chemicals in pine posts given the double-diffusion treatment by standing them upright in barrels. The effects of certain treating variables—nature of the chemicals, strength of solutions, treating times, temperature, and species of wood—are discussed.

A review of earlier work on this method and a brief discussion of its possible advantages and disadvantages are given to help explain the objectives of the work described.

This report is written primarily for those who have a scientific interest in wood preservation. It may serve as a general guide to other investigators who may wish to place double-diffusion-treated posts in their test plots.

FOR A NUMBER OF YEARS the Forest Products Laboratory has been investigating[2] the double-diffusion method of wood preservation in an attempt to find a treatment that can be applied with simple equipment and without heat, yet one that gives long-lasting protection even when the wood is used under severe leaching conditions.

In the double-diffusion method, green wood is soaked in an aqueous solution of one chemical, then in an aqueous solution of another chemical. The two chemicals diffuse into the wood, then react to form an insoluble, toxic precipitate.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] This project was conducted partially under Research and Marketing Act funds. The author gratefully acknowledges the assistance of H. G. Roth of the Forest Products Laboratory and George Fahlstrom and Jean Baernstein, formerly of the Forest Products Laboratory, in the conduct of these tests.

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In this report the word "diffusion" is used in its broader sense to denote spontaneous spreading of either the solute or the whole solution. In physical chemistry the term is restricted to the movement of isolated molecules of a solute through a solvent; the latter phenomenon is referred to in this report as "true diffusion."

When waterlogged wood is immersed completely in an aqueous solution, the movement of the solute into the wood is an example of true diffusion. Green wood, however, is not waterlogged; it contains air spaces, and, when it is completely immersed in a solution, the ingress of the solute is influenced by a certain amount of internal movement of the whole solution. When green wood is only partially immersed in a solution, some of the solution rises by capillary action into the unsubmerged, or emergent, part of the piece. This movement is accelerated by evaporation of water from the emergent portion.

When two chemicals that are capable of reacting to form a precipitate[3] are allowed to diffuse into green wood, their individual diffusion pressures decrease as the reaction takes place. Only the unreacted portion of whichever chemical is in excess will retain appreciable motility. This drop in diffusion pressure along with mechanical hindrance by the precipitate was recognized at the outset as a possible barrier to the attainment of a satisfactory distribution of the precipitate. The objective of much of the work was to find conditions that would lead to the best distribution possible in a treatment of this type.

[3] In addition to the desired toxic precipitate, another compound is formed as a byproduct of each reaction. These byproducts are of no interest because they are soluble and are not toxic to fungi or termites.

It is apparent that, while the double-diffusion treatment can be described in simple terms, the theoretical aspects are involved. A detailed fundamental study of such systems has not been undertaken.

This method offers certain advantages and disadvantages when compared with other methods. Some of the advantages are:

1. Only simple equipment is required.
2. No heat is required.
3. The chemicals that can be used are relatively inexpensive.
4. The operator needs no technical training or experience.
5. The cost of transporting the ingredients of the treating solution to the site of treatment is low because water is used as the solvent; the active ingredients are dry solids that can be shipped in light, inexpensive containers, such as multiwall paper bags.
6. In contrast to wood treated with a single water-soluble chemical, double diffusion-treated wood appears to retain its resistance to decay under wet conditions.
7. The treated wood is clean, odorless, and paintable.
8. Because green wood is used, the handling and storage required for seasoning are eliminated.

This also avoids losses due to decay that may occur during seasoning.

Some disadvantages of the method are:

1. The fact that the treatment is applied to green wood has been cited as an advantage. This may also be a disadvantage in that prompt treatment after cutting may not be convenient.
2. The treatment cannot be applied in freezing weather unless the equipment is heated, a requirement that would detract from the simplicity of the operation.
3. Considerable time is required to obtain the absorptions that are believed to be necessary. This may be relatively unimportant in the treatment of low-cost forms of wood, such as fence posts, in inexpensive equipment, such as barrels, but would constitute a more serious drawback in the treatment of such items as lumber and poles in more costly containers.
4. In contrast to treatment with oil preservatives, the double-diffusion treatment affords no mechanical protection from weathering or checking.
5. As compared with a treatment with a single chemical, the method requires a second container, a second solution, and additional handling of the wood.

In view of these advantages and disadvantages, the method appears to be more practical for some products and for some geographical areas than for others.

The first studies[4] of this method consisted of laboratory leaching and decay tests of blocks cut from near the outside of short sections of posts that had been treated with several combinations of chemicals. Chemical analyses of blocks before and after severe leaching showed that the precipitates were highly permanent under these conditions. Laboratory decay tests of the leached blocks showed that they were resistant to attack by several wood-destroying fungi.

Field tests were started on wood treated with several combinations that had given encouraging results in the laboratory. Fence posts were chosen as the principal test material, partly because of their low cost and partly because several features of the method pointed to the treatment of fence posts as a likely field of usefulness. It was recognized that such treatment might be made on a farm by an individual farmer or at a cooperatively owned or commercial plant. If the treatment were made on a farm, barrels or used oil drums would be the containers most easily obtained, in which case the posts standing in the containers would be only partly submerged in the solutions. If the treatment were made in a plant, complete immersion of the posts in solutions contained in tanks would be the most likely procedure. It was decided to use this second method in treating the first series of test specimens.

[4] Baechler, R. H. Resistance to Leaching and Decay Protection of Various Precipitates Formed in Wood by Double Diffusion. Proc. AWPA No. 37 pp. 23–31 (1941). Forest Products Laboratory Report No. R1290, 7 pp.

Field Test Encouraging

In the spring of 1941, a group of 100 green, peeled, southern pine posts were treated with copper sulfate followed by sodium arsenate, the aim being to deposit copper arsenate within the wood. After being seasoned, these posts were installed in a test fence in the Harrison Experimental Forest near Saucier, Miss. Late in 1941, some 2- by 4-inch stakes, 18 inches long, were treated by complete immersion in copper sulfate, then some were immersed in sodium arsenate solution and the rest in sodium chromate solution. This series was designed to compare the effectiveness of copper arsenate and copper chromate.

While this is not a report on the results of field tests, it may be stated that after 11 years the performance of these test posts and stakes has been highly encouraging. Only one failure has occurred and only a small percentage of test specimens have shown attack.[5, 6]

This investigation was interrupted by World War II. When non-military projects were resumed after the war, it was decided that, because of an increased interest in the possibility of treating posts satisfactorily on the farm, first attention should be given to a study of the method using barrels. This made it necessary to defer further experiments on full-immersion treatments of posts in tanks and treatments of other wood products.

The effectiveness of any preservative treatment of wood depends upon the nature of the preservative and the thoroughness of the treatment; that is, the amount of the preservative retained and its distribution. The results on posts treated by the barrel method, therefore, could not be translated directly into results that might be obtained by complete immersion in tanks, nor would they show the exact service life that might be obtained from products of other size, shape, or species when treated with the same chemicals. However, it was believed that field tests on the treated posts would serve to compare the different chemical combinations among themselves and also give some idea of how the more effective combinations applied by the barrel method compare with standard preservatives applied by a pressure process. This would show whether the basic principle was sufficiently promising to justify the cost of a more thorough investigation that would involve its application to various products and by various means.

With this general plan in view, most of the treatments to date have been confined to barrel treatments of pine posts. Since 1946 a number of treatments have been made in the field, and the posts have been installed in tests. They will be inspected annually and reports of inspections will be published periodically.

Other smaller-scale treatments have been made in Madison and the posts have been analyzed to determine the absorption and distribution of chemicals obtained under different conditions. The data in this report have been obtained chiefly by means of these small-scale laboratory treatments.

The main variables in these tests have been the chemicals, the concentrations of solutions, and the treating schedules. There have been some variations in other details, such as species of wood, completeness of bark removal, depth of solution, application of supplementary treatment to tops, retardation of drying after treatment, and others. Most treatments, however, have followed a fairly uniform pattern and, unless otherwise stated, the data reported have been obtained on pine posts treated by the following procedure:

Green posts 6½ to 7 feet long, which had been cut within several days, or within several weeks and then stored unpeeled under slow-drying conditions, were completely peeled. A 6-inch piece was cut from the butt end of each post. The posts were stood upright, butt down in the first solution contained in a wooden barrel or steel drum about 30 inches deep. Enough solution was prepared so that it practically filled the barrel with the posts inserted. After a period of one to several days, the posts were transferred to the second solution and stood butt down. Each post was rinsed with about a pint of water upon removal from each solution. After the desired period in the second solution, the

[5] Blew, J. O. Comparison of Wood Preservatives in Mississippi Post Study (1952 Progress Report). Forest Products Laboratory Report No. R1757, 13 pp.

[6] Blew, J. O. Comparison of Wood Preservatives in Stake Tests (1952 Progress Report). Forest Products Laboratory Report No. R1761, 35 pp. Illus.

posts were removed and stood top down to season.

After being seasoned, the posts were ripped lengthwise and a disk one inch thick was cut at each foot along the half-post. The disks from a post were ground together to form a composite sample that was analyzed to determine the absorptions of both chemicals. Three posts from each series or treatment were analyzed to obtain an average value for absorption. In addition, a disk was cut from near the ground line, near the middle, and near the top of one post of a series. These disks were analyzed to obtain data on distribution.

Significant Properties of Chemicals Used

The nature of the starting chemicals affects the toxicity of the precipitate, the rate of diffusion, and the distribution of the chemicals in the wood.

Most of the chemical combinations used have consisted of the sulfate of copper, zinc, or nickel in the first bath and one of several sodium salts in the second bath. Copper sulfate is probably the most effective on the basis of cost and it is likely that the precipitated copper compounds are at least as effective as the analogous compounds of nickel and zinc.

Because copper sulfate solutions are corrosive to steel, a container of some substance like wood or concrete is needed. Also, if the second stage of the treatment is not carried far enough to precipitate most of the copper, the copper remaining in soluble form may accelerate the corrosion of staples and wire.

In laboratory tests, nickel salts appear to be about as toxic to fungi as the analogous copper salts. They have the advantage of being less corrosive. With the addition of a small amount of a corrosion inhibitor, such as sodium dichromate, nickel sulfate solutions can be held in an iron drum. However, nickel sulfate normally costs considerably more than copper sulfate and the price differential has increased during the past years. At the time this report is being written, the use of nickel sulfate is restricted by the Government.

Zinc sulfate appears to be definitely less toxic than copper and nickel sulfates, but has the compensating advantage of being relatively noncorrosive. The solution, with no corrosion inhibitor added, can be held in an iron drum.

In certain treatments arsenic acid has been added in small amounts to the sulfate solutions used in the first stage and sodium chromate has been used in the second stage. The precipitate formed in such cases is a mixture of the arsenate and chromate of whichever metal is used. The ratio of arsenic to metal in the first solution tends to decrease during treatment.

Sodium salts that have been used to precipitate the metallic ion include chromate, fluoride, arsenate, borate, and phosphate. All produce alkaline solutions except sodium fluoride, which yields a solution that is practically neutral. When sodium fluoride and copper sulfate solutions are used, either one may be applied first. In treatments involving one of the alkaline sodium salts, much better penetration of chemicals is obtained if the metallic salt is used first and the sodium salt second.

All of the sodium salts used in these treatments, except sodium borate, are salts of fairly strong acids and are made to react with salts of certain weakly basic metals. Strongly basic metals cannot be used because they are low in toxicity. Since precipitates formed from weak bases and weak acids would hydrolyze in the presence of water, salts of fairly strong acids are generally used in order to form precipitates that will not hydrolyze appreciably.

The acid ions which seem suitable vary in certain significant properties. The arsenate ion contributes most to the toxicity of the compound formed, but the use of sodium arsenate would offer some hazard to the operator. Until handling methods of proven safety are developed, the use of this chemical should be restricted to commercial treatments.

Fluoride and borate ions contribute to toxicity and appear to be suitable for use on the farm. Sodium fluoride forms a precipitate with copper sulfate, but not with the sulfates of zinc and nickel. Sodium borate forms precipitates with the sulfates of copper, zinc, and nickel.

The phosphate ion does not contribute to toxicity; its sole function is to insolubilize the toxic copper. However, it may have some advantages for treating such products as grape stakes and hop poles that are used in contact with growing plants. Such plants might be injured by an excess of a toxic chemical used in the second stage of the treatment, because it might form a deposit on the surface of the wood on drying.

The most practical absorption for any given combination of chemicals, taking into consideration initial cost and service life, will not be known until the results of extensive field tests are available. In most of the field tests that have been started and in most of the experimental laboratory treatments, the aim has been to obtain a total absorption of chemicals within the range of absorptions used in pressure treatments with salt preservatives. This range is approximately 0.3 to 1.5 pounds of chemical per cubic foot of wood.

When the three metallic salts (copper, nickel, and zinc) were applied under similar conditions, the data on absorptions and distributions did not show marked differences.

It has been pointed out that when green posts are stood upright in an aqueous solution, the solute enters the wood as a result of several distinct phenomena. Diffusion pressure, which may be described as the tendency of a solute to distribute itself uniformly in a solvent, causes the individual molecules of the dissolved chemical to migrate into the water contained in the wood. In addition to this, there is some movement of the whole solution into capillary openings in the ends and to some extent in the sides of the post. The capillary rise is especially rapid on the external surface of the post because of the fact that the semicapillaries (capillaries that are split longitudinally) are free from the restrictions that exist in the complete capillaries within the wood. When a peeled green pine post about 7 feet long is stood in a solution of copper sulfate having a depth equal to approximately one-third the height of the post, the blue color of the solution begins to spread up the outside of the post in less than an hour. Occasionally streaks of color reach the top of the post within 24 hours, An inward movement of chemical from the colored surface takes place simultaneously, but this movement is slow compared with the capillary rise on the surface. However, the solution on the surface becomes more concentrated by evaporation of water and, as a result, the radial migration of chemical by true diffusion is accelerated. This movement probably continues during the seasoning of the treated post until the water phase is no longer continuous.

Factors Affecting Absorption

From theoretical considerations, one would expect a practically linear relation between the concentration of the first solution and the amount of chemical absorbed in unit time. The data in table 1 show reasonable agreement with this theory. In one day's steeping time, the absorptions of copper sulfate obtained from different solutions were:

Concentration Percent	Absorption Lb. per cu. ft.	Ratio Conc./abs.
11.3	0.56	20.2
9.7	.49	19.7
7.95	.38	20.9
5.8	.28	20.7

The absorption of the second chemical is influenced by the amount of the first chemical already present in the wood. The amount of copper sulfate in wood affects the rate of absorption of disodium phosphate in the following manner:

Copper sulfate present Lb. per cu. ft.	Concentration of disodium phosphate solution Percent	Time Days	Absorption of disodium phosphate Lb. per cu. ft.
0.28	6.3	4	0.97
.69	6.1	4	.45
.23	3.06	8	.75
.38	3.06	8	.50

For reasons not understood, the absorption of the second chemical is more erratic than that of the first. It seems unlikely that any simple general relations would apply to the absorptions of the second chemicals in the various combinations.

The relation between steeping time and absorption of the first chemical is exponential, the rate decreasing with time. The data are too meager for mathematical analyses. The curve of absorption over time does not show a sharp break within the first several days—the time that will yield adequate absorptions and would be used in practical treatments. A few calculations based on data from table 1 are given below:

Concentration of solution Percent copper sulfate	Time Days	Absorption of copper sulfate: Total Lb. per cu. ft.	Absorption of copper sulfate: Per day Lb. per cu. ft.
11.3	1	0.56	0.560
11.3	2	.94	.470
5.7	2	.44	.220
5.7	3	.57	.190
5.7	4	.69	.172
5.8	1	.28	.280
5.8	2	.43	.215
5.8	3	.67	.223
3.07	2	.24	.120
3.07	2	.23	.115
3.07	4	.38	.095

In these treatments only a few posts were treated at one time. The true diffusion of chemicals into the post, which would tend to weaken the solution, was nearly compensated by the concentrating effect of evaporation. The solutions, therefore, underwent small changes; namely, 11.30 percent to 11.26 percent, 5.76 percent to 5.71 percent, and 5.82 percent to 5.84 percent. When a barrel is filled with posts, as it would be in practical treatments, and when moderately concentrated or concentrated solutions are used, a decided drop in the concentration of the solution takes place during the treatment. Accordingly, a sharper decrease in rate of absorption than is shown by the above data will be found in such treatments.

As has been pointed out, the rate of absorption of the second chemical is influenced by the presence of the first chemical as well as by other factors. Under constant conditions, it would be expected that an exponential relation exists between steeping time and absorption of the second chemical. Not enough data are avaliable to check the validity of this theory.

The relations between temperature and the rate of true diffusion have been developed, but they could not be expected to hold exactly in treatments made as described. The mobility of the ions increase and the viscosities of the solutions decrease with an increase in temperature. Both changes tend to increase the rate of true diffusion. Increase in temperature also accelerates the rate of evaporation from the emergent part of the post and in that way accelerates the capillary rise of solution. However, evaporation would also be affected by the relative humidity of the air and its rate of circulation. In practice the chemical would be taken up faster at higher temperatures, but the exact rate would vary. Perhaps the effect of temperature is sufficient so that some allowance should be made for the extremes that may be encountered under practical conditions. Most of the treatments to date have been made under the moderate temperatures prevailing in spring and autumn. Controlled tests to show the effect of temperature have not as yet been undertaken.

The species of wood has a decided effect on the treatability by any process. Because of the meagerness of the data on species other than pine, no broad statements are possible concerning the treatability of various species by double diffusion. Experience to date indicates that regardless of species, round posts having an appreciable thickness of sapwood, when treated under favorable conditions, will absorb amounts of chemicals within the range of those used in commercial treatments. The distribution pattern shown by color reactions varies considerably with species and this may be expected to affect the protection afforded by a given amount of chemical.

The relation between the degree of seasoning and treatability has not as yet been studied. In the initial stages of this investigation, the treatability of green pine posts was found to be far superior to the treatability of kiln-dried posts. It is now accepted that the posts should be as green as possible, but the practical question of how long cut posts may be held before treatment remains to be answered. Pine posts have been treated satisfactorily several weeks after cutting. In order to retard drying, the posts were close-piled prior to treatment and peeled just before treatment. A 6-inch piece was sawed from the butt end of each post just before it was inserted into the solution. It is believed that this step is important in the treatment of pine posts which have been held long enough for a layer of resin to form on the end. This step seems less important in the treatment of nonresinous species and might not be necessary if the posts were treated within a few days after cutting.

There are other variables that are known to affect treatability, but have not been studied in detail. The rate of growth, for example, appears to have an effect; in a few tests slow-grown southern pine treated more slowly than rapidly grown wood having wide bands of springwood. The number, size, and distribution of knots will affect distribution of the chemicals and perhaps also their absorption. The rate of rise of color up the outside of a post appears to be more rapid in posts cut in spring than in similar posts cut in fall.

Table 1 shows that absorptions within the range of those used in commercial pressure treatments may be obtained in one day. As will be explained later, a longer treating time may be preferred for its effect on distribution.

Factors Affecting Distribution

The final distribution of a precipitate is governed by a number of factors, such as absorption, rate at which the absorption was obtained, nature of the reacting chemicals, properties of the wood, and conditions of seasoning. The data are inadequate to per-

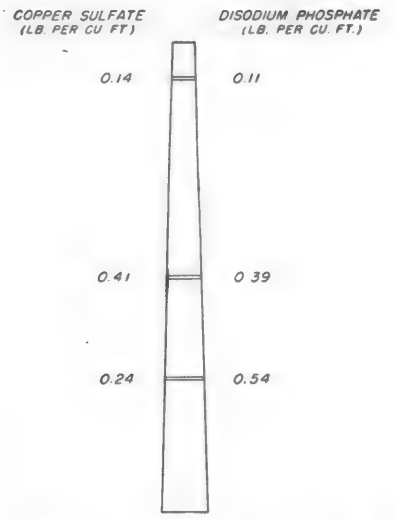

Figure 1.—Distribution of copper and phosphate in a jack pine post stood 2 days in 5 percent copper sulphate and 4 days in 3.5 percent disodium phosphate. (Average absorption in pounds per cubic foot was 0.33 for copper sulphate and 0.42 for sodium phosphate.)

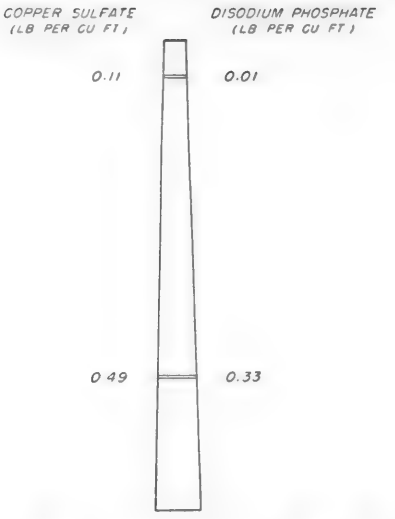

Figure 2.—Distribution of copper and phosphate in a jack pine post stood for 2 days in 6 percent copper sulphate and 2 days in 6 percent disodium phosphate. (Average absorption in pounds per cubic foot was 0.45 for copper sulphate and 0.27 for sodium phosphate.)

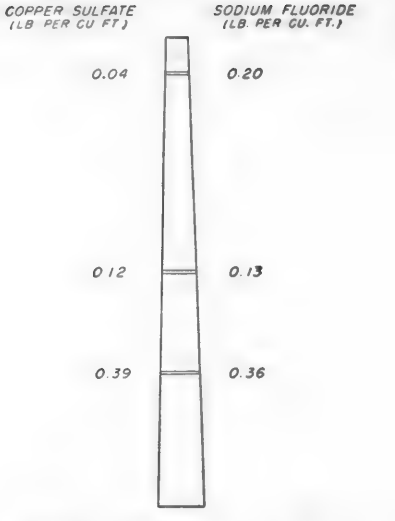

Figure 3.—Distribution of copper and fluoride in post stood 2 days in 5 percent copper sulphate and 5 days in 4 percent sodium fluoride.

mit mathematical analyses of any isolated factor, and only general trends will be indicated. Even these general statements will need to be accompanied by exceptions because of the complexity of the subject.

As a general rule, distribution is improved by increasing absorptions and by lengthening the time required to obtain a given absorption; that is, by diluting the treating solution. The distribution of a specific ion is further influenced by the amount of the other ion present. The distribution of a given ion tends to be more uniform when there is a deficiency of the other ion.

A considerable movement of the first ion may take place before the second ion reaches the scene. As a result, the first ion tends to show a more uniform distribution than the second. The distribution of the second ion may be improved by adding it in excess. Since a large excess is undesirable from the standpoint of cost, it appears more practical to limit this excess and accept some maldistribution of the second ion. The amount of chemical in the upper part of the post may be increased by inverting it. This of course requires additional labor, but it may be worth-while under certain conditions. Some examples of the distributions which are obtained with different ratios of the two reacting chemicals in posts given butt treatment only are given in the figures to follow.

Figure 1 shows the results of analyses of disks taken from the ground line, the middle, and near the top of a post treated with copper sulfate and an excess of disodium phosphate.

There are a number of phosphates of copper having definite compositions and different ratios of copper to phosphate. For the purpose of this discussion, this reaction will be assumed:

$$CuSO_4 + Na_2HPO_4 = Na_2SO_4 + CuHPO_4$$

The reacting weights are: copper sulfate ($CuSO_4$), 159.6; disodium phosphate (Na_2HPO_4), 142.2. The total absorption of the phosphate is in excess of the theoretical amount required, yet some deficiency exists in the upper disk.

Figure 2 shows the distribution in a post treated with the same chemicals but with conditions controlled to produce an over-all deficiency of phosphate. In this post there is a marked deficiency of phosphate near the top.

Under some conditions the distribution of the second ion may be more uniform than that of the first. Figure 3 shows the distribution of copper and fluoride in a post containing a large excess of the fluoride that was used in the second stage. The reacting weights in this case are copper sulfate ($CuSO_4$), 159.6; sodium fluoride (2NaF), 84.

The relatively large amount of fluoride in the top disk may be attributed not only to the large excess present, but also to the motility of the fluoride ion and to the neutrality of sodium fluoride solutions. Copper fluoride is soluble in weak acids and, since copper sulfate solutions are slightly acid, a precipitate of copper fluoride does not form in a copper sulfate solution until an appreciable amount of sodium fluoride has been added.

As has been indicated, dilute solutions and treating schedules of several days in each solution tend to yield better distribution of the desired precipitate than stronger solutions and a treating schedule of one day in each solution. The effect of the treating time on the distribution cannot be treated mathematically at present. Data are lacking on different posts in which the same amounts of the same chemicals have been introduced under different conditions of time and concentration.

Effects of Reacting Chemicals

The nature of the reacting chemicals naturally affects the distribution of the precipitate. The favorable properties of sodium fluoride for use as a precipitant of copper have been pointed out. At the other extreme lies sodium chromate. The chromate ion tends to be fixed on cellulosic fibers and the final distribution of chromate is definitely poorer than that of the other acid ions. The incomplete precipitation of zinc or nickel in the upper part of the post is believed to be unimportant because loss by leaching would probably be slow. However, if copper is not precipitated completely, the soluble copper salts may corrode staples and wires. Several means of combatting this condition are being tested. For this combination of chemicals it probably is advisable to invert the post during part of the time in the chromate solution.

The position of the post during seasoning likewise affects the final distribution of chemicals. When three posts were treated together and placed in different positions for seasoning it was found that a post which was stood

Table 1.--Absorption of chemicals by jack pine posts

Treating schedule	Absorptions
	Lb. per cu. ft.
1 day in 11.3 percent $CuSO_4$[1] + 2 days in 7.5 percent Na_2HPO_4[2]	0.56 $CuSO_4$ + 0.28 Na_2HPO_4
2 days in 11.3 percent $CuSO_4$ + 4 days in 7.5 percent Na_2HPO_4	.94 $CuSO_4$ + .56 Na_2HPO_4
2 days in 5.7 percent $CuSO_4$ + 2 days in 6.1 percent Na_2HPO_4	.44 $CuSO_4$ + .24 Na_2HPO_4
3 days in 5.7 percent $CuSO_4$ + 3 days in 6.1 percent Na_2HPO_4	.57 $CuSO_4$ + .26 Na_2HPO_4
4 days in 5.7 percent $CuSO_4$ + 4 days in 6.1 percent Na_2HPO_4	.69 $CuSO_4$ + .45 Na_2HPO_4
3 days in 3.18 percent $CuSO_4$ + 3 days in 3.06 percent Na_2HPO_4	.18 $CuSO_4$ + .17 Na_2HPO_4
5 days in 3.18 percent $CuSO_4$ + 5 days in 3.06 percent Na_2HPO_4	.40 $CuSO_4$ + .43 Na_2HPO_4
8 days in 3.18 percent $CuSO_4$ + 8 days in 3.06 percent Na_2HPO_4	.58 $CuSO_4$ + .50 Na_2HPO_4
1 day in 9.7 percent $CuSO_4$ + 7 days in 7.5 percent Na_2HPO_4	.49 $CuSO_4$ + 1.07 Na_2HPO_4
1 day in 5.8 percent $CuSO_4$ + 4 days in 6.3 percent Na_2HPO_4	.28 $CuSO_4$ + .97 Na_2HPO_4
2 days in 5.8 percent $CuSO_4$ + 8 days in 6.3 percent Na_2HPO_4	.43 $CuSO_4$ + 1.18 Na_2HPO_4
3 days in 5.8 percent $CuSO_4$ + 12 days in 6.3 percent Na_2HPO_4	.67 $CuSO_4$ + 1.55 Na_2HPO_4
2 days in 3.07 percent $CuSO_4$ + 4 days in 3.06 percent Na_2HPO_4	.24 $CuSO_4$ + .37 Na_2HPO_4
2 days in 3.07 percent $CuSO_4$ + 8 days in 3.06 percent Na_2HPO_4	.23 $CuSO_4$ + .75 Na_2HPO_4
4 days in 3.07 percent $CuSO_4$ + 8 days in 3.06 percent Na_2HPO_4	.38 $CuSO_4$ + .50 Na_2HPO_4
1 day in 7.95 percent $CuSO_4$ + 4 days in 3.22 percent NaF	.38 $CuSO_4$ + .28 NaF
2 days in 7.95 percent $CuSO_4$ + 4 days in 3.22 percent NaF	.63 $CuSO_4$ + .25 NaF
2 days in 7.95 percent $CuSO_4$ + 7 days in 3.22 percent NaF	.58 $CuSO_4$ + .34 NaF

[1] Copper sulfate.

[2] Disodium phosphate.

upright, butt-down, showed the least amount of chemical in the top. A post seasoned top-down showed a much heavier treatment of the top. Somewhat less chemical was found in the top and more at the ground line of a post that was laid flat to season.

Retarding the loss of moisture by keeping the posts covered for about a month after treatment makes for more uniform distribution.

The height of liquid in the barrels naturally affects the distributions of chemicals in the posts. The treatment of the top is improved as the height of liquid is increased. Optimum absorption of total chemical is not necessarily found in the submerged portion of the post, as would be expected. The second chemical is nearly always found in decreasing amounts from bottom to top, but the heaviest absorption of the first chemical is generally found somewhat above the liquid line. As a result, this part of the post commonly shows the heaviest total absorption.

The distribution of chemical that might be considered ideal will doubtless vary with conditions of exposure. In a humid climate in which the tops of posts are subject to decay, some treatment of the top is necessary for the maximum life of the post. On the other hand, it seems logical to handle the treatment so as to retain as much chemical as possible in the lower part of a post that is to be used in a semi-arid region in which only the ground line is subject to decay.

Peeling Requirements

It has been known for some time that when a green post is treated with only one soluble chemical, satisfactory distribution may be obtained without peeling the post. Up to the present, double-diffusion treatments of unpeeled posts have resulted in unsatisfactory distribution. However, complete peeling does not appear to be necessary. Recent experiments have shown that if narrow strips of bark are removed longitudinally from four sides of a post, the results of treatment are similar to those obtained on completely peeled posts. It should be repeated here that the data in this report are on completely peeled posts.

The foregoing discussion of distribution has concerned longitudinal distribution only. Radial distribution has been followed chiefly by stain tests on cross sections, supplemented by a limited number of chemical analyses. These tests show that the chemicals are found almost entirely in the sapwood, although in some cases, some penetration of heartwood is found in the lower part of the post. In lightly treated parts of the post, the treatment seems to be confined to the springwood.

When absorptions fall within the range of those used in commercial pressure treatments with salt-type preservatives, a pine post generally shows complete sapwood penetration at the ground line and incomplete penetration at the top. A disk taken from near the top nearly always shows a ring of solid treatment around the outside with discontinuous streaks of treated springwood inside this ring. The thoroughness of treatment at the top depends largely upon the total absorption and the time used to obtain that absorption. Complete treatment of the top can be obtained only through the additional cost of heavier-than-normal absorptions or the additional handling required to invert the post during part of the immersion periods.

The performance of posts of a few hardwood species that have been treated and placed in test has been inferior to that of pine posts treated with the same chemical combinations. It is believed that the difference can be explained only in part by differences in treatability. The fungi that attack hardwoods appear to be more tolerant to these chemicals than the fungi that attack pine. Research is needed to find chemical combinations that are best suited to treating hardwoods.

Studies of the treatments of products other than posts are in progress, but no results of significance are available at present.

Further Research Needed

As has been stated, the results of field tests on pine posts and stakes treated with adequate amounts of chemicals have been excellent to date.

In view of this fact, and because of the practical advantages of this method, further research should be done on this type of treatment.

Some of the questions that require further study have already been mentioned. The barrel method for treating round pine posts has received major attention so far, but even this application of the basic principle needs additional study. More detailed data are needed to determine accurately the relations between certain treating variables and the distribution of the desired precipitate.

It has been shown that when pine posts are given a butt treatment only and when relatively small amounts of chemicals are introduced, the protection of the upper part appears to be inferior to the protection of the ground line. There are a number of ways of counteracting this tendency, such as inverting the post during part of the time in one or both solutions, giving the top a brush treatment, or retarding the seasoning of the treated post. The most practical measure—taking into account cash outlay, labor, and effectiveness of treatment—remains to be determined.

In full-immersion treatments with tanks, the time factor has a greater bearing on cost than in treatments made with cheaper equipment, such as barrels. For this type of application it is desirable to know the minimum immersion periods required to give acceptable results with products of different sizes.

The application of the two chemicals in either dry or paste form offers practical advantages in certain situations and therefore merits investigation.

A study of the effect of a "rest" period between the two applications might lead to improved distribution of the precipitate.

The effect of the moisture content of the wood should be studied because it relates to the time that may be allowed to elapse between cutting and treating.

More information is also needed on the effect of temperature on absorption and distribution.

Much remains to be done on the treatability of various species and also on the effectiveness of the various toxic precipitates in different species. Field tests need to be conducted under various climatic conditions and in soils of various types. Such tests should include not only untreated controls but also material treated by standard commercial methods so that, ultimately, comparisons can be made on the basis of annual cost.

Discussion

James A. Greenwald (Cuprinol Division, Darworth, Inc.): Is heat required to get the two chemicals into solution?

Mr. Baechler: No. Heat reduces the time required to dissolve the chemicals but is not necessary.

W. L. Meek (University of Illinois): Have you had any experience with hardwoods treated by this method?

Mr. Baechler: Some hardwoods have been treated by this method, but the results were generally less favorable. This is probably due to the hardwoods absorbing different retentions and also to the fact that different fungi are involved in the decay of hardwoods. It appears that heavier absorptions are required to protect certain hardwoods.

R. M. Carter (North Carolina State College): Is any fixation effect encountered with dinitrophenol, sodium fluoride, sodium bichromate, sodium dichromate, sodium arsenate, and similar compounds in salt mixtures.

Mr. Baechler: Some fixation effect has been demonstrated although not to an equal degree in these particular compounds.

P. B. Mayfield (Barrett Division, Allied Chemical & Die Corp.): How much time is required for the two soaking treatments?

Mr. Baechler: The time required varies with the species. Only one day in each solution is required to give fairly good absorptions in pine posts, but two days time or more in each solution is recommended in the South; increasing the time not only increases absorptions but improves distribution.

Mr. Mayfield: What depth of penetration can be obtained in southern pine posts?

Mr. Baechler: The depth of penetration depends largely upon the absorption. At ½ to 1 lb. per cubic foot, most of the sapwood in the bottom part, including perhaps some heartwood, and some of the sapwood in the top part will be penetrated.

Recovery of Organic Solvents From Wood Pressure Impregnated with Solutions of Copper Naphthenate or Pentachlorophenol

MONIE S. HUDSON

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Volatile solvents used as the vehicle for impregnation of wood with organic fungicides such as copper naphthenate or pentachlorophenol, can be successfully removed from the wood and recovered by means of the Vapor Solvent Recovery Process. This operation not only effects substantial saving in the cost of treatment by recovery of the solvent, but also eliminates surface deposits of "bleeding" or "blooming" that are built up on the outside of the wood as the solvent evaporates under the usual methods of steaming or air drying to remove solvent. Because of the clean surface produced by the Vapor Solvent Recovery Process, the wood can be painted or laminated after treatment without experiencing the difficulties that are encountered in present practice.

TODAY WOOD PRESERVATIVES comprise three widely differing groups of materials, namely, (1) coal tar distillates and solutions of these with coal tar or petroleum, (2) inorganic salts, (3) single organic compounds with active wood preservative characteristics.

For the most part, substances of the first group are heavy, dark and oily, complex mixtures of aromatic hydrocarbons and their derivatives. They are applied to wood in relatively large quantity (about 20 percent of the wood weight); depending for their action on a great reservoir of toxic material to protect the wood over long periods of time, even though leaching and evaporation are continually acting to deplete them. Because of the large quantities of liquid required for impregnation, wood so treated has a number of objectionable properties for certain uses. It is subject to exudation of variable quantities of the preservative that collects on the surface, and forms sticky tar-like deposits which make it impossible to handle the treated wood without soiling clothing and other materials coming into contact with it, and which make the surface totally unfit for satisfactory painting. These coal tar materials are largely used undiluted for the treatment of wood although in some instances, such as for railroad crossties, coal tar distillates may be diluted with coal tar or heavy petroleum to lessen the cost. These oily type materials are the oldest in point of use.

The inorganic salts were brought into use to answer the problem posed by the lack of cleanliness of creosoted wood. Although they have served well for this purpose, they have not given as satisfactory preservative performance as creosote because of their loss from the wood by leaching with water, making it necessary for the writers of the American Wood Preservers specifications for these salts, to point out that they should not be used where leaching is an important factor. These water-soluble salts depend for their preservative action on the high toxicity to wood destroying organisms of relatively small amounts of chemical in the wood; in the neighborhood of one to five percent of the wood weight. In treatment of wood with these chemicals or chemical mixtures, the preservative is dissolved in water and the solution is pumped into the wood by the conventional pressure processes. After treatment the water is removed by air seasoning or kiln drying. The oldest of the inorganic salts is zinc chloride. Its use began about the same time as that of creosote, about 100 years ago. During the past 20 years, there have been introduced a number of new inorganic salts such as chromated zinc chloride, Wohlman Salts, zinc meta arsenite, Celcure, Greensalt, Boliden Salt and Chemonite.

The third group of chemicals listed above is made up of organic chemical compounds which have been found to possess a high degree of toxicity for wood destroyers, and at the same time are highly permanent in the treated wood because of their physical properties of water insolubility and low vapor pressure. These materials are the fruits of research to develop preservatives tailor-made specifically for their action against wood destroying organisms, in somewhat the same manner as sulpha drugs were developed for specific action against streptococcus organisms in the field of medicine. These materials have been found to impart good protection to wood against fungi and other wood destroying organisms in concentrations in the neighborhood of one percent of the dry weight of the wood. They possess the advantage over the water soluble salts of being virtually insoluble in it, and except for difficulties arising from the use of organic solvents necessary to carry them into the wood; wood treated with them is clean and paintable. The most widely used commercially of these chemicals today in the field of wood preservation are copper naphthenate and pentachlorophenol. Their commercial

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use as wood preservatives dates back no more than about 20 years.

For impregnation of wood with these materials, the preservative may be dissolved in any of a wide range of organic solvents, but the tendency has been toward the use of very light, volatile solvents in an effort toward obtaining clean paintable surfaces on the treated wood. In the use of these light solvents, several difficulties have been encountered as follows:

(1) Light, water-white organic solvents are as a rule much more expensive than the heavier, darker products.

(2) Such solvents are usually very inflammable and must be removed from the wood before it is ready for use.

(3) The light solvents tend to bring the preservative to the surface as they evaporate, leaving heavy resinous deposits in the case of copper naphthenate, or a heavy encrustation of pentachlorophenol crystals on the surface, known as "blooming".

No ready solution has been available for the first two of these disadvantages, but by the use of anti-blooming agents the "blooming" of pentachlorophenol has been overcome by the addition of plasticizers to the treating solution; however, the use of these anti-blooming agents adds very materially to the cost of the preservative treatment.

Through a program of development work which began in 1949, the Research Department of Taylor–Colquitt Co. working with the Cuprinol Div. of Darworth, Inc. on copper naphthenate, and with the Chapman Chemical Co. on pentachlorophenol, evolved a process for removal and recovery of the impregnating solvent, that at the same time, eliminates the high surface concentrations of preservative which cause paint defects such as discoloration, and bleed-through of preservative.

A number of different means of solvent recovery such as steam stripping and heating in vacuum ovens were considered in the early part of this work, but it was found that by using a modification of the Vapor-Drying Process (1)(2)(3) far superior results could be obtained, not only in the efficiency of solvent recovery but also as to the surface condition of the timber from which the solvent had been recovered.

Apparatus and Operation

Figure 1 illustrates the equipment in which this vapor process of solvent recovery is carried out. The central part of this figure shows a conventional wood preserving cylinder with condenser attached. Figure 2 shows an experimental application of the process to wood impregnated with pentachlorophenol. This chart shows first the impregnation of a charge of kiln dried, southern pine lumber with pentachlorophenol dissolved in xylol. At the start of the treatment initial air pressure of 40 psi was established in the treating cylinder. The cylinder was then filled with a solution of pentachlorophenol in xylol and the pressure was brought to 100 psi over a period of one hour. After holding this pressure for one hour, it was released and the cylinder was emptied and a vacuum of about 24 inches of mercury was applied for one hour. Part of the charge so impregnated was subjected to recovery of solvent by the Vapor Process beginning when the "after treatment" vacuum was broken. This vapor solvent recovery operation consisted in heating the impregnated lumber in the vapor of xylol. To produce this vapor, xylol from the "fresh solvent" storage tank, shown on figure 1, was pumped into the bottom of the cylinder until it had reached track level, as indicated on the figure. The steam heating coils in the cylinder were then turned on to cause the xylol to boil. Vapor arising from the boiling xylol contacted the wood and condensed on it, dissolving from its surface excess pentachlorophenol. This condensed liquid carried the dissolved pentachlorophenol down into the solution in the bottom of the cylinder by dripping back into it. The pentachlorophenol being relatively non-volatile at the existing temperature, remained in the solution in the bottom of the cylinder, while the xylol was again free to vaporize and continue extraction of the charge. Condensation of this hot xylol vapor brought the cylinder temperature up to about 260 deg. F. by the end of one hour; by which time considerable heat had been stored up in the wood. This stored heat was then utilized to vaporize part of the xylol from the solution that had been injected into the wood during pressure treatment, by employing a vacuum cycle of one hour at 24 inches of mercury. During the vacuum the cylinder heating coils were cut off to stop the boiling of the xylol in the pool in the bottom of the cylinder. At the end of the hour's vacuum, the heater coils were again turned on for an hour heating in vapor, and at the end of that time the solution, containing pentachlorophenol extracted from the wood, was pumped from the cylinder to the used solvent storage tank, before the final vacuum period of one hour was impressed. When solvent recovery cycles

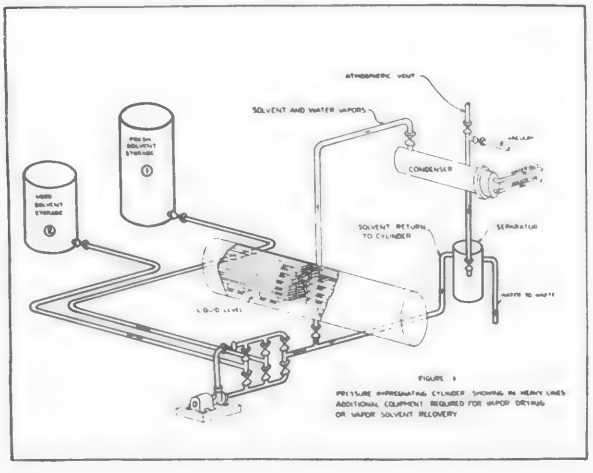
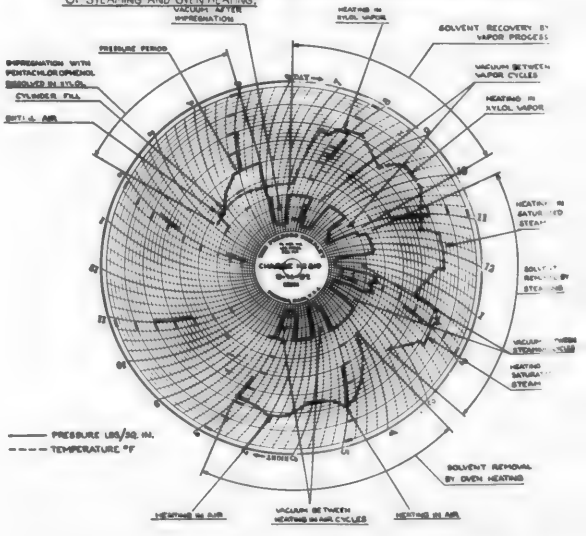


FIGURE 1
PRESSURE IMPREGNATING CYLINDER SHOWING IN HEAVY LINES ADDITIONAL EQUIPMENT REQUIRED FOR VAPOR DRYING OR VAPOR SOLVENT RECOVERY

FIG. 2 OPERATING CONDITIONS USED IN TESTS TO COMPARE VAPOR PROCESS FOR RECOVERING SOLVENT FROM TREATED WOOD WITH PROCESSES OF STEAMING AND OVEN HEATING.



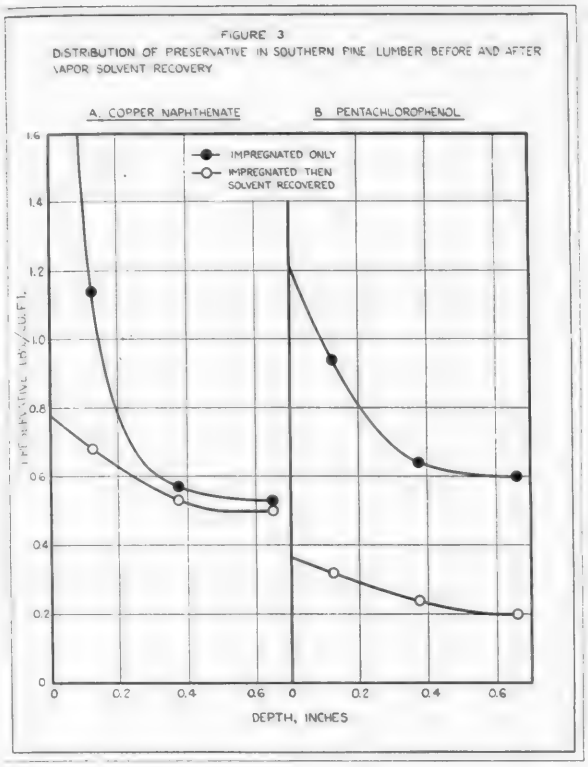
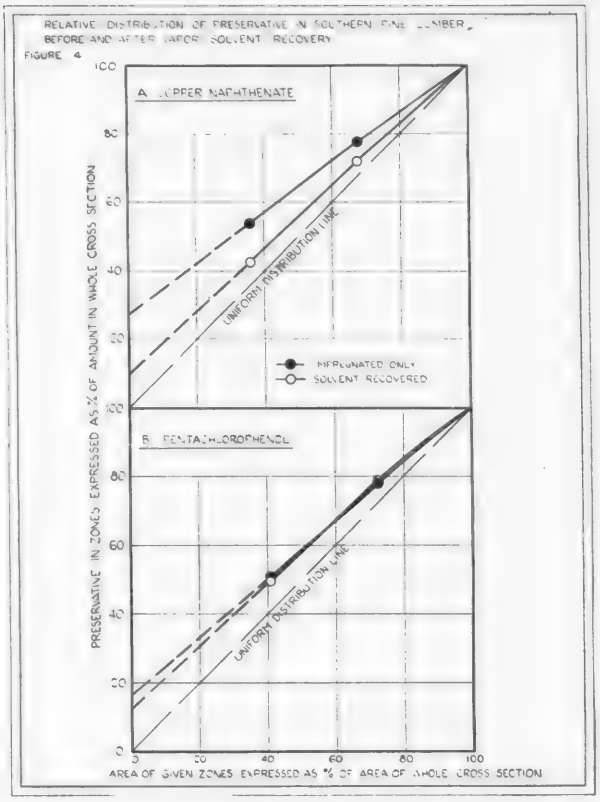


FIGURE 3
DISTRIBUTION OF PRESERVATIVE IN SOUTHERN PINE LUMBER BEFORE AND AFTER VAPOR SOLVENT RECOVERY
A. COPPER NAPHTHENATE
B. PENTACHLOROPHENOL
IMPREGNATED ONLY
IMPREGNATED THEN SOLVENT RECOVERED
DEPTH, INCHES


RELATIVE DISTRIBUTION OF PRESERVATIVE IN SOUTHERN PINE LUMBER, BEFORE AND AFTER VAPOR SOLVENT RECOVERY
FIGURE 4
A. COPPER NAPHTHENATE
UNIFORM DISTRIBUTION LINE
IMPREGNATED ONLY
SOLVENT RECOVERED
B. PENTACHLOROPHENOL
UNIFORM DISTRIBUTION LINE
PRESERVATIVE IN ZONES EXPRESSED AS % OF AMOUNT IN WHOLE CROSS SECTION
AREA OF GIVEN ZONES EXPRESSED AS % OF AREA OF WHOLE CROSS SECTION

are carried out on subsequent charges, the liquid to be boiled in the cylinder is drawn in from the "used solvent" storage, and the operation is carried out in the same manner as described above when fresh solvent was used. As charge after charge is extracted with this liquid, the preservative concentration in it increases until it reaches a level as high as that in the solution used for pressure impregnation of the wood. When this point has been reached, the solution is pumped from the "used solvent" storage to the impregnating working tank, not shown on the drawing, for use in impregnation of charges.

Just as in the regular Vapor-Drying Process, the high temperature vapor boils some water from the wood, in spite of the fact that the wood might have been kiln dried or air dried previously. This water is conveyed as vapor over to the condenser, by excess xylol vapor that does not condense on the wood; there the mixture is condensed and the two liquids that are produced are separated by the continuous decanter or separator shown beneath the condenser in figure 1. The water is discharged and the xylol flows back to the pool of liquid in the bottom of the cylinder. The moisture content of southern pine after a solvent recovery cycle of the usual length will be about 4 to 8 percent. It can be returned to higher moisture content if desired by steaming at atmospheric pressure for 30 minutes to one hour. The finished wood will be found to be virtually stress free.

Processing Schedules and Results

Table 1 shows typical processing schedules that are employed in processing 2-inch thick southern pine lumber treated with copper naphthenate or pentachlorophenol. For general purpose lumber the final retention aimed at in these treatments was about ½ lb./cu.ft. for copper naphthenate, and about ¼ lb./cu.ft. for pentachlorophenol. It will be noted from the copper naphthenate data that in order to obtain a final retention of about ½ lb./cu.ft. it was necessary to impregnate the charge with ¾ lb./cu.ft. since the recovery operation removed ¼ lb. Approximately 75 percent of the copper naphthenate put into the wood during impregnation remained aftre solvent recovery had been completed. In the case of the pentachlorophenol a retention of ¾ lb./cu.ft. of preservative during treatment yielded a final retention of only ¼ lb. after solvent recovery. Only about 35 percent of the pentachlorophenol originally put into the wood remained at the end of the solvent recovery operation. The reason for this difference in behavior of the two chemicals can be attributed to the fact that part of the copper naph-

Table 1—TYPICAL PROCESSING SCHEDULES AND TREATING RESULTS FOR SOUTHERN PINE LUMBER SUBJECTED TO VAPOR SOLVENT RECOVERY AFTER IMPREGNATION

	Copper Naphthenate	Penta-chlorophenol
Dimensions of lumber	2" x 8"	2" x 4"
Impregnation with Preservative Solution:		
Approx. concentration of preservative in xylol solution	9.5%*	10%
Initial air, psi	50	25
Preservative pressure, psi	150	100
Preservative temperature, °F	Atmospheric	Atmospheric
Duration of preservative pressure, Hrs.	1.5	2
Vacuum after impregnation, In. Mercury	24	24
Duration of vacuum, Hrs.	1	1
Retention of preservative solution, lbs./cu. ft.	8.1	7.2
Retention of preservative, lbs./cu. ft.	0.76	0.74
Solvent Recovery by Vapor Process		
One hour periods of heating in vapor at 260 to 270° F, total hrs.	2	2
One hour periods of vacuum at 24 inches between vapor heating periods, total hrs.	2	2
Retention of solvent after recovery, lbs./cu. ft.	0.3	0.4
Retention of preservative after solvent recovery, lbs./cu. ft.	0.57	0.26

*0.75% metallic copper.

Figure 6.—Mated specimens of southern pine impregnated with pentachlorophenol and solvent removed by following methods: S by steaming; SR by vapor process; and OH by oven heating.

thenate becomes fixed to the lignocellulose and is not removed by the extracting action of vapor solvent recovery whereas the pentachlorophenol undergoes no fixation and therefore is extracted much more easily. Working with higher retentions of copper naphthenate, in the neighborhood of 2½ lbs./cu.ft. after impregnation, it has been found that after a solvent recovery operation such as shown in table 1, about ½ of it remained, which indicates that a saturation point of copper fixation by the wood is reached and after that occurs, more and more of the chemical can be extracted.

The impregnation conditions such as initial air, and intensity and duration of preservative pressure would be varied as is customary in the usual impregnation procedures for different species or dimensions of lumber, or to obtain different retentions. For example, with Douglas fir or red oak the pressure period would be considerably longer than that used on southern pine. The solvent recovery cycle for Douglas fir of 2 inch thickness runs from 1½ to 2 times as long as that shown for southern pine in table 1; but for red oak the vapor processing time would be about the some as shown in this table. The reason for the longer solvent recovery cycle on the Douglas fir is that the upper grades of lumber of this species usually contain more than 90 percent heartwood, which is more difficult to penetrate than sapwood, and once the penetration has been obtained the difficulty of removing the solvent is correspondingly great. Generally speaking, the harder the wood is to impregnate, the harder it is to get the solvent back out. This has also been found to be the case with southern pine heartwood. In some of the work that has been done with southern pine, it was found that charges containing large amounts of heartwood should be treated with a lower differential pressure between that of the initial air and the preservative pressure, to keep from treating this heartwood, in order to obtain satisfactory solvent recovery in the length of time indicated in table 1. In charges containing large amounts of heartwood, 50 psi initial air and 75 psi preservative pressure, giving a differential of 25 lbs., is sufficient to treat the sapwood of the lumber satisfactorily but prevents treatment of the heart, thus making it possible to quickly recover the solvent.

Distribution of Preservative in Southern Pine

Figure 3 shows typical distribution curves for the preservative in southern pine lumber impregnated and solvent recovered by schedules like those in table 1. This information represents average values that were obtained by analysis of many samples of wood, by zoning specimens taken from the wood after treatment, into outer ¼ inch, second ¼ inch, and remainder and analyzing the zones for the preservative with which the wood was impregnated. The curves for copper naphthenate in this figure show that most of the approximately 25 percent which was removed from the wood, came from the surface and outer ¼ inch while in the interior there was virtually no removal of the preservative. In the case of the pentachlorophenol, the approximately 65 percent that was removed, came from the entire cross-section in proportion to the amount present in each of the zones. The data of figure 3 have been converted to terms of percent of the total volume of the cross-section represented by each zone, and amount of preservative in the zones expressed as percent of the amount in the whole cross-section; and are plotted in figure 4. This figure illustrates more clearly the difference in behavior of the copper naphthenate and pentachlorophenol impregnated wood when subjected to the Vapor Solvent Recovery Process. In this figure, the dashed 45° lines indicate the condition that would obtain with solution uniformly distributed throughout the cross-section. A study of this figure reveals the following:

1. Distribution of both copper naphthenate and pentachlorophenol show departures from absolute uniformity, which would be expected because of impedance to penetration offered by the wood structure.
2. The distribution of pentachlorophenol in the "impregnated only" wood is more uniform than that of the copper naphthenate. This evidently results from the fact there is selective adsorption of copper naphthenate by the lignocellulose which leaves a higher proportion of the preservative in the outer zones as the preservative enters the wood.
3. The uniformity of distribution of the pentachlorophenol is unchanged by the solvent recovery operation, which means that the pentachlorophenol removed as indicated in figure 3, moved out as liquid at the same concentration that it had in the wood

Table 2—COMPARATIVE COST OF REMOVAL OF SOLVENT FROM SOUTHERN PINE LUMBER AFTER IMPREGNATION WITH COPPER NAPHTHENATE OR PENTACHLOROPHENOL

	Vapor Solvent Recovery		Steaming		Air Drying	
	Pounds	¢	Pounds	¢	Pounds	¢
A. Copper Naphthenate						
Solvent per cu. ft.	0.25	0.006	1	0.023	8	0.185
per 1000 FBM	20.8	0.48	83.3	1.92	667	15.39
Copper naphthenate						
per cu. ft.	0.5	0.105	0.57	0.120	0.63	0.132
per 1000 FMB	41.7	8.76	47.5	9.98	52.5	11.03
Cost of removing solvent per 1000 FMB		7.50		5.50		1.50
Total cost excluding cost of impregnation per 1000 FBM		16.74		17.40		27.92
B. Pentachlorophenol						
Solvent per cu. ft.	0.25	0.006	1	0.023	8	0.185
per 1000 FBM	20.8	0.48	83.3	1.92	667	15.39
Pentachlorophenol						
per cu. ft.	0.25	0.053	0.30	0.063	0.38	0.080
per 1000 FBM	20.8	4.37	25.0	5.25	31.7	6.66
Antiblooming agent						
per cu. ft.	None required		0.30	0.045	0.38	0.057
per 1000 FBM			25.0	3.75	31.7	4.75
Cost of removing solvent per 1000 FBM		7.50		5.50		1.50
Total cost excluding cost of impregnation per 1000 FBM		12.35		16.42		28.51

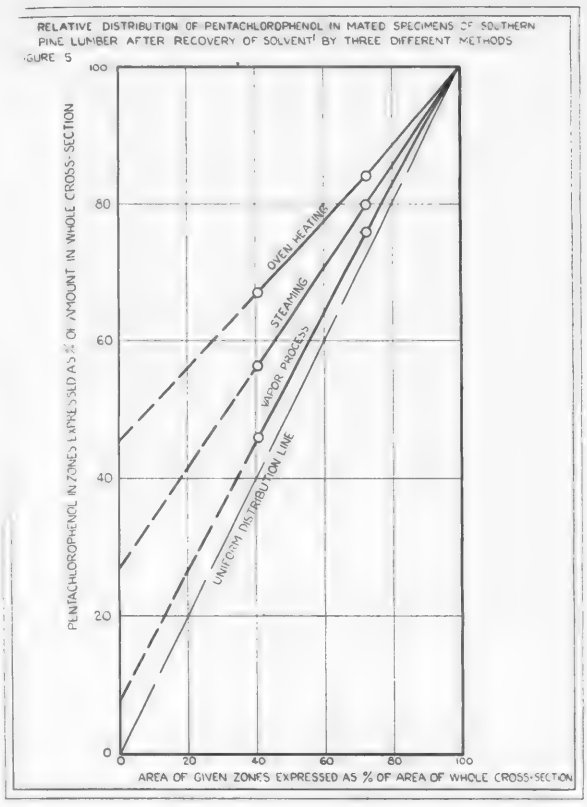

RELATIVE DISTRIBUTION OF PENTACHLOROPHENOL IN MATED SPECIMENS OF SOUTHERN PINE LUMBER AFTER RECOVERY OF SOLVENT BY THREE DIFFERENT METHODS
FIGURE 5
PENTACHLOROPHENOL IN ZONES EXPRESSED AS % OF AMOUNT IN WHOLE CROSS-SECTION
AREA OF GIVEN ZONES EXPRESSED AS % OF AREA OF WHOLE CROSS-SECTION
OVEN HEATING
STEAMING
VAPOR PROCESS
UNIFORM DISTRIBUTION LINE
0
20
40
60
80
100

Figure 7.—Paint test on southern pine impregnated with pentachlorophenol showing condition after one year exposure on test fence. Boards with letter "A" were vapor solvent recovered after impregnation. Boards with letter "B" were aired dried one to two months after impregnation before painting.

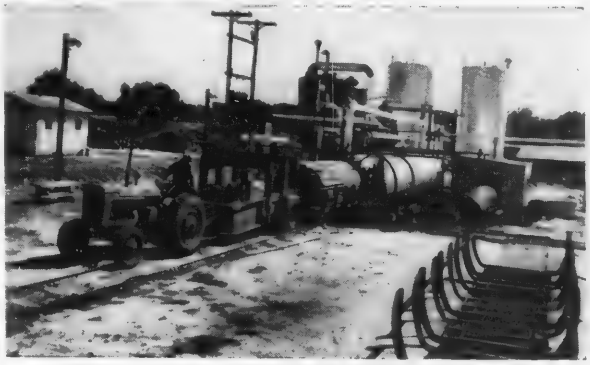


Figure 8.—Vapor solvent recovery plant, Brice Wood Preserving Co., Archer, Fla.

originally after treatment. As will be shown later, it has been found that if the solvent from the pentachlorophenol treated wood is allowed to evaporate into the air, or is removed by steaming that the distribution becomes much less uniform. This can be explained by the fact that although the pentachlorophenol moves toward the surface in liquid at the same concentration as that injected into the wood; at the surface it is concentrated as the solvent evaporates into the air, or to the vacuums after steaming, since the steam is not a solvent for the pentachlorophenol. On the other hand, the pentachlorophenol moved to the surface in the Vapor Process is extracted by the condensing solvent from the surface of the wood maintaining the relatively uniform distribution that was originally present.

4. The distribution of copper naphthenate is improved by the vapor solvent recovery operation, being brought to a substantially uniform condition. As mentioned above, this evidently results from fixation of copper naphthenate in the wood, so that it does not move out as liquid at the same concentration as that in the wood. The reason that its concentration is reduced in the outer 1/4 inch, which accounts for the improvement in uniformity, is evidently because in that region the wood's affinity for copper naphthenate has become saturated and the excess can therefore be removed.

Comparison with Other Processes

Returning to figure 2, it will be seen that cycles of steaming and oven heating to remove solvent are also shown. These were run on mated lots of lumber that were impregnated as shown at the start of the chart. One of the mated lots had already been vapor solvent recovered as discussed above. As indicated on the chart, the steaming was carried out in saturated steam at 260 deg. F. for periods of one hour, alternated with vacuum periods of one hour. The oven heating was also carried out at 260 deg. F. in one hour periods, alternated with one hour periods of vacuum. After these processing schedules both the steamed and the oven heated lumber still retained about 1 lb./cu.ft. of solvent, which was several times the amount left after vapor solvent recovery.

In figure 5 is shown the relative distribution that was found in the mated specimens of pentachlorophenol treated lumber after being processed by the three different methods of solvent recovery given in figure 2. As was pointed out in connection with the discussion of figure 4, steaming causes considerable divergence from the uniform distribution that is obtained by vapor solvent recovery, while oven heating causes an even greater lack of uniformity of distribution. It has already been explained that this is caused by surface build-up of pentachlorophenol moved out of the wood under the influence of heating and vacuum. The pentachlorophenol is not extracted from the surface by the steam, although a sizable amount of it must be blown off by release of the steam pressure, since in oven heating much more of the preservative is left in the surface. Tests have been made to determine whether anti-blooming agents would prevent this movement of pentachlorophenol to the surface. These tests showed that the anti-blooming agents were ineffective in preventing this. Their only function was found to be that of "flatting" the layer of pentachlorophenol built up on the surface so that it no longer appeared as "blooming" from crystals standing out on the surface, but by mutual solubility reduced the surface deposit to a less conspicuous amorphous condition.

Cleanliness and Paintability

Figure 6 is a photograph of three mated boards from charges solvent recovered by the cycles indicated in figure 2. It will be seen that the specimen from which the solvent was removed by the vapor process was free of objectionable surface deposits. This specimen was in such a condition that it could be painted with white paint immediately after treatment, without experiencing subsequent damage to the paint coat through discoloration by—or bleed-through of—, the pentachlorophenol. As will be seen from the photograph, both the oven heated and steamed specimens were in a completely unusable condition with respect to cleanliness of the surface. Both of these specimens had areas of mottled gummy deposits that were sticky to the touch, and there were also patches of moderate to heavy blooming of pentachlorophenol crystals scattered over the surface of the wood. Moreover, the entire surface was badly discolored. This wood could not be satisfactorily painted since the gummy deposits are miscible with paint and would quickly discolor it.

Figure 7 shows mated southern pine boards from which solvent was merely allowed to evaporate into the air for a period of 1 to 2 months after treatment, and others which were vapor solvent recovered after treatment. To determine the effect on paintability, these boards were painted with one coat of Pittsburgh white undercoater, and 24 hours later with one coat of Pittsburgh Titanic outside white and then exposed on a test fence for one year. Discoloration of the paint in the specimens that were not vapor processed is very evident.

Suitable Solvents

The Vapor Solvent Recovery Process has been carried out using a number of different solvents such as Stoddard solvent (mineral spirits) VM&P naphtha, xylol, toluol, high flash coal tar naphtha, perchloroethylene and trichloroethylene. Physical operation of the process has been found to be equally satisfactory with any of these chemicals although economic considerations favor the mixtures of compounds that can be obtained as fractions with fairly narrow boiling ranges, rather than the pure compounds. There is some preference for fractions containing aromatic compounds rather than straight aliphatics for this operation, both because of their better solvency for pentachlorophenol and because of the fact that they more readily dissolve the natural resins of the wood whose removal in the vapor processing operation improves the quality of the surface from the standpoint of paintability.

Vapor-Drying and Solvent Recovery

The Vapor Solvent Recovery operation can be carried out on wood that has been Vapor-Dried as well as air seasoned or kiln dried. For 2-inch, green southern pine lumber, alternating cycles of about 10 hours Vapor-Drying, comprising one hour heating in vapor alternated with one hour vacuum cycles, repeated five times, is adequate for drying prior to impregnation with copper naphthenate or pentachlorophenol. The impregnation with preservative is carried out in the same vessel in which the wood is Vapor-Dried and the subsequent solvent recovery operation is also carried out there. By utilizing the Vapor-Drying Process before impregnation, and Vapor Solvent Recovery after impregnation, it is possible, starting with stump green lumber, to turn it out impregnated with either copper naphthenate or pentachlorophenol, free from solvent, and at less than 10 percent moisture content, in about 19 hours. The lumber can be painted or laminated or otherwise handled after treatment without encountering any of the difficulties that are experienced with wood treated with oil borne preservatives by present methods of processing.

Costs

In table 2 is shown a comparison of the cost of removal of solvent from southern pine lumber impregnated with copper naphthenate or pentachlorophenol. Information in this table is predicated on the use of a wood preserving plant equipped for Vapor Solvent Recovery or for steaming, having a capacity of from 5,000 to 10,000 FBM of timber.

The solvent used is mineral spirits and its cost is assumed to be 15 cents per gallon, which weighs about 6.5 lbs. It is assumed that the wood is impregnated with 8 lbs. of solvent per cubic foot containing the desired amount of copper naphthenate or pentachlorophenol. Retention of solvent after Vapor Solvent Recovery or steaming is based on information developed in experimental work on these processes. For air drying, stacking of the impregnated wood on a seasoning yard for at least six weeks after treatment is assumed. In air drying all of the solvent introduced in impregnation is lost since it evaporates into the air.

The retention of copper naphthenate in the vapor solvent recovered lumber is assumed to be ½ lb./cu. ft. containing 8% metallic copper, and costing 21 cents per lb. Retention of this preservative, after removal of solvent by steaming, was determined from relative distribution values that have been obtained in experimental work. The relative distribution so found was used to calculate the average retention for the cross-section that would be necessary to give the same copper naphthenate retention in the center of the wood, as is present in the vapor solvent recovered wood having an average retention of ½ lb./cu. ft. The amount calculated in this manner was for the steam recovered wood, 0.57 lbs./cu. ft. of copper naphthenate. The amount required for the air dried wood as calculated in this manner was 0.63 lbs. per cu. ft.

The cost of removing the solvent includes the amortization, depreciation, and maintenance of a plant to do this work, at usual rates that apply to wood preserving equipment. It includes also the cost of steam for heating, the plant operator's time, etc. The $1.50 per M shown as cost for removing solvent under the air drying procedure takes into consideration the removal of the treated material to a yard and stacking for air seasoning to allow the solvent to evaporate.

The cost of carrying out the impregnation process is not included since this would be the same regardless of the method of processing after impregnation. As will be seen from the total cost figures shown at the foot of the copper naphthenate table, the vapor solvent recovery operation costs less than recovery by steaming. The air drying operation, because of its great loss of solvent is the most expensive. Although steam solvent recovery can be carried out for about the same cost as Vapor Solvent Recovery, the steam processed product does not possess the very decided advantage of surface cleanliness and paintability that is obtained by the use of the Vapor Solvent Recovery Process.

In the case of pentachlorophenol, the retention of the preservative used in calculating cost is ¼ lb./cu. ft. for the vapor solvent recovered material. The average retentions for the steamed and air dried wood are 0.30 and 0.38 lbs./cu. ft. respectively. These amounts would be necessary to give the same concentration of pentachlorophenol in the center of the timber so processed, as that obtained at the center of the vapor solvent recovered material having an average retention of ¼ lb./cu. ft. The cost of the pentachlorophenol is assumed to be 21 cents per lb. In present practice when pentachlorophenol is used in light solvents it is necessary that an anti-blooming agent be added. In table 2 it is considered that the anti-blooming agent is added in

(Continued on page 230)

Air Seasoning of California Redwood

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A study was made of the effect which spacing between piles has on the factors which must be considered in planning and operating redwood air-drying yards. The results show that considerable savings could be realized by spacings much wider than were in common use. A comparison was also made between the cost of air drying and kiln drying in order to determine the point at which it becomes more economical to dry lumber in a kiln than in a yard.

Introduction

BETWEEN 250 AND 300 million feet of redwood lumber is kiln dried at the producing mills annually. Of this total, approximately 70 per cent is sinker or heavy lumber with a moisture content in excess of 150 per cent when sawn. The remaining lumber ranges downward to a low moisture content of about 40 per cent.

The water which must be removed from this lumber to bring it down to a kiln dried condition of 10 per cent moisture content approximates one billion pounds. Removal of such a quantity of water from redwood is done at considerable expense to the industry. It is the purpose of this paper to report the results of recent investigations into the influence of several aspects of pre-air seasoning on the cost of drying redwood.

Almost all of the redwood sawmills segregate the lumber to be kiln dried into two or three groups according to its moisture content and other characteristics which affect the drying time. The segregated lumber is then placed into yards to dry in the air until most of the water which can be removed by the atmosphere is gone from the wood.

The pre-air drying is undertaken primarily because it costs less to remove a large part of the free water in that way and the milder yard drying, as compared to kiln drying, results in less degrade from seasoning defects. It also greatly reduces the range of moisture content of lumber going into the kilns, thereby simplifying the problems involved in kiln drying, and increasing the uniformity of the final moisture content.

Because of the high initial moisture content and the slow drying conditions in the yards, most of which are located in the coastal regions of Northern California, pre-air seasoning periods of several years have not been uncommon for redwood. According to

Figure 1.—Redwood pre-air seasoning yard. The photograph shows an end view of the test drying yard. In the part of the yard shown, the piles, formed by packages stacked four high, are spaced eight feet apart.

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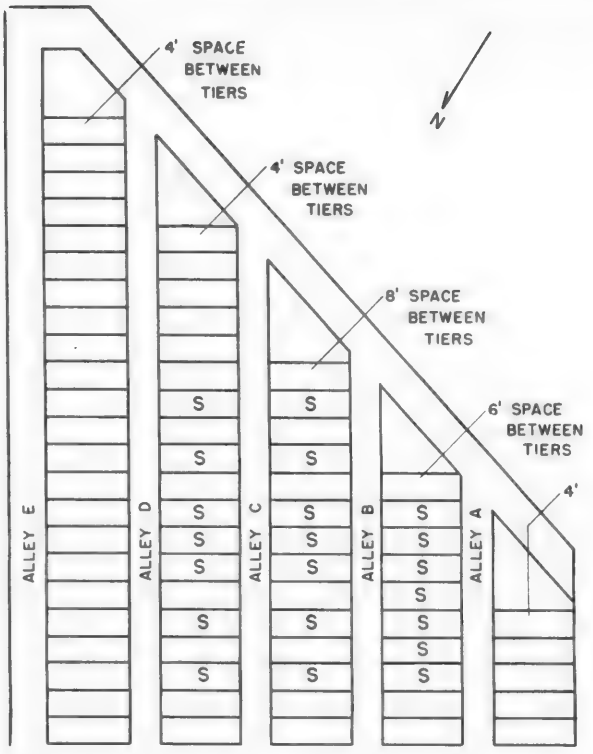


Figure 2.—Plan view drawing of the test yard. The small rectangular divisions represent blocks of lumber piles. The long dimension of the packages of lumber is parallel to the alleys. Blocks containing an "S" are those in which test data were collected with samples as indicated in Figure 3.

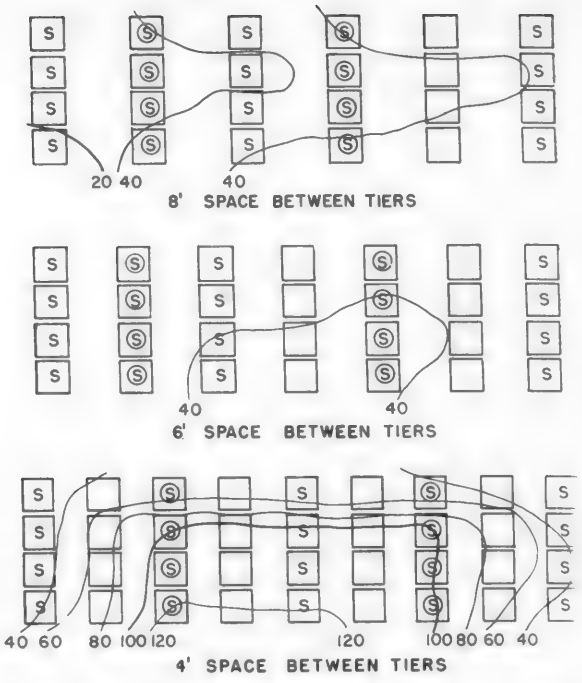


Figure 3.—End view drawing of blocks of 1 in. sinker redwood showing the uniformity of drying which would be expected after 270 days of air drying on each of the three spacings studied. An initial moisture content of 200 per cent was assumed for all of the lumber. Sampled packages in which the "S" is circled were sampled in the 1 in. sinker test blocks only.

Peck (1), there is no active air-drying season in the Redwood Region. In an effort to reduce the long period of pre-air seasoning, studies were begun several years ago on the factors which might influence the rate of drying.

The present study was approached on the basis that the air-drying yards should be so planned that the air movement around each piece of lumber is at a maximum within economic limits. Determination of these limits was the objective of the study. This approach involved a consideration of the following yard characteristics which influence circulation around the individual pieces of lumber.

1. Width of packages
2. Height of piles
3. Sticker thickness
4. Orientation of piles in relation to prevailing winds
5. Spacing between piles

The optimum conditions for the first four of these variables can be readily ascertained for each yard. Width of packages and height of piles are usually based upon the handling equipment to be used. Generally a nominal four foot package width is used and the packages, which are also usually four feet high are stacked four or five high, depending upon the stacking equipment and stability of the piles.

Sticker thickness is commonly ¾ in. However, at some operations a thinner sticker (½ in.) is used because it permits more lumber to be included in each kiln charge.

Because the broad sides of the piles of stuck lumber present fairly impentrable surfaces to air currents, the piles are generally arranged with their long dimension parallel to the prevailing winds. Most frequent air change in the yard and maximum air movement in the spaces surrounding the individual pieces of lumber is obtained when the wind is parallel to the long open area-ways between piles.

The yard characteristic which has the greatest effect on air circulation, and therefore on rate at which the lumber dries, is the spacing between the piles. Early tests indicated that the pile spacings of two feet and less which were in common use were inefficient. Using these tests as a guide, the California Redwood Association in cooperation with the Arcata Redwood Company undertook the following test to determine the economic limits of pile spacing in the air drying yards.

Test Procedure

A test yard was laid out as shown in Figure 2. Blocks composed entirely of one of each of the following segregations were included in each of the three spacings:

1. 1 in. sinker
2. 1¼ in. sinker
3. 1 in. light
4. 2 in. light

Selected boards 18 and 20 feet long and eight inches wide with a moisture content of 175 to 250 per cent for sinker samples and 60 to 100 per cent for light samples, with a ring count of 30 to 50 rings per inch were cut into four foot lengths. A two-inch section was removed between each four foot length for determination of initial moisture content. The samples were placed in the center of the packages as indicated in Figure 3. The more extensive sampling was undertaken on 1 in. sinker to determine the effect of spacing on uniformity of drying of packages as well as rate of drying.

Sample boards within the center of the packages were weighed before being placed into the packages and periodically thereafter until the lumber was removed from the yard. The moisture content of the sample boards at the time of periodic weighings was determined.

[1] Peck, Edward C., 1950 Air Drying of Lumber. U. S. Dept. of Ag. Forest Products Laboratory No. R1657.

In evaluating various drying procedures, both in the yard and kiln, it is necessary to compare the efficiency of different drying conditions. The best way of comparing efficiency of drying conditions is by determining their effect upon the rate of drying. However, the rate at which a piece of lumber dries is dependent not only upon the drying conditions to which the lumber is subjected, but also upon the moisture content of the lumber itself. Therefore, in comparing various drying conditions, the effect of sample moisture content on the rate of drying must be eliminated. Since the use of samples of exactly equal moisture content would be extremely difficult, a simple mathematical method of eliminating the effect of sample moisture was used in the analysis of the results.

Manson (1) has shown that the ratio between the drying rate and the average moisture content of lumber drying under uniform drying conditions tends to remain constant as the moisture content of the lumber decreases. This ratio, which is termed the Drying Rate Factor, can be expressed by the following equation:

$$(1)\ \text{Drying Rate Factor} = \frac{\text{Loss of Moisture per Unit of Time}}{\text{Average Moisture Content}}$$

Because the Drying Rate Factor approximates a constant under constant drying conditions, it has been very useful in designing optimum schedules in kiln drying. However, the Drying Rate Factor remains a constant only if the lumber continues to lose moisture until it approaches zero per cent moisture content, which would require drying under conditions in which the equilibrium moisture content approaches zero per cent. While such conditions are possible in kilns, atmospheric conditions in air-drying yards preclude equilibrium moisture contents close to zero per cent.

In the course of the study, it was found that with constant drying conditions, the ratio between the rate of loss of moisture and the residual moisture in the wood in excess of the equilibrium moisture content of the atmosphere in which the wood was drying tended to remain constant. This relationship was reduced to a factor called the Corrected Drying Rate Factor which is expressed by the following equation:

$$(2)\ \text{Corrected Drying Rate Factor} = \frac{\text{Loss of Moisture per Unit of Time}}{\text{Average Moisture Content Less Equilibrium Moisture Content}}$$

The Corrected Drying Rate Factor, since it tends to remain constant for a given drying condition, can be used to compare samples of unequal moisture content. It can also be used to predict the rate at which lumber subjected to given conditions will dry by substituting the Corrected Drying Rate Factor for those conditions into Equation (2) and solving for the final moisture content, assuming any initial moisture content.

Corrected Drying Rate Factors were calculated for each of the sample boards placed in the experimental yard. The equilibrium moisture content for the period of the test was estimated from a U.S. Department of Commerce Local Climatological Summary to be 20 per cent. Corrected Drying Rate Factors were used to predict the moisture content to which lumber in the different locations would dry in various time periods, assuming that all lumber of one segregation had the same initial moisture content. Thus the Corrected Drying Rate Factor provided a method of comparing the various drying conditions of the test yard.

Results

It was found that the wider the spaces between piles, the faster and more uniformly the lumber dried. Figure 3 shows the effect of three pile spacings on the uniformity of drying 1 in. sinker. The illustrations were prepared assuming that all of the sinker lumber had an initial moisture content of 200 per cent, and the moisture content of each package at the end of 270 days was calculated by the use of the Corrected Drying Rate Factors for the individual packages.

In the end view of the packages on the four foot spacing there is a very pronounced pattern showing vertical and horizontal gradients in the moisture content within the block. There is very little pattern in the blocks with the six and eight foot spacings.

These patterns can be evaluated by using the Corrected Drying Rate Factor for the slowest drying package on each spacing to predict the time required to dry all of the lumber of each spacing to various moisture contents. This can be done because the slowest drying package in any block will determine when the entire block is ready to be transferred to the kiln.

[1] Manson, Byrne C., 1950, Quality Control and the Improved Seasoning Processes of the Redwood Industry. FPRS Proceedings 4:29–35.

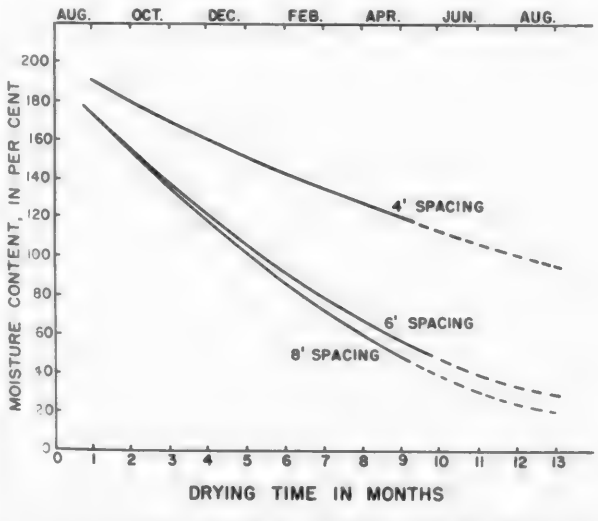


Figure 4.—Curves showing the moisture content to which 1 in. sinker redwood lumber will air dry as a function of the time it is in the drying yard in blocks with 4, 6 and 8 ft. pile spacings.

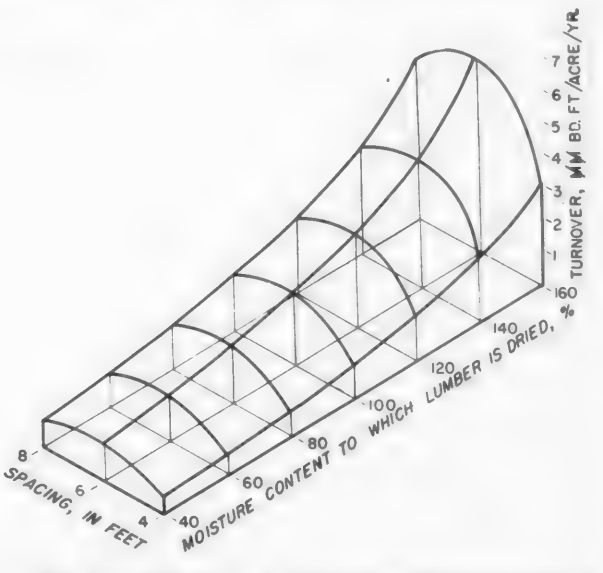
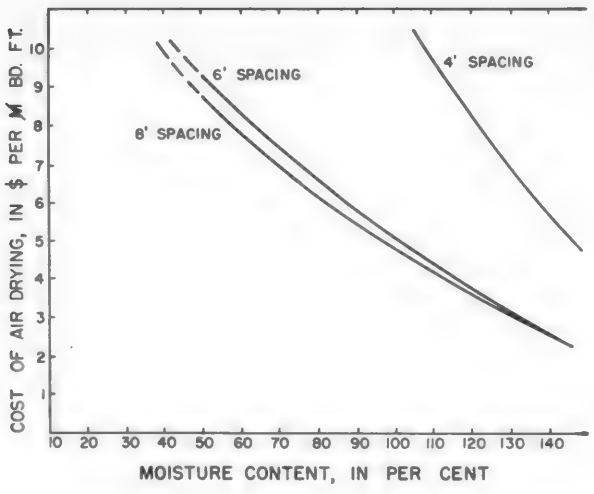
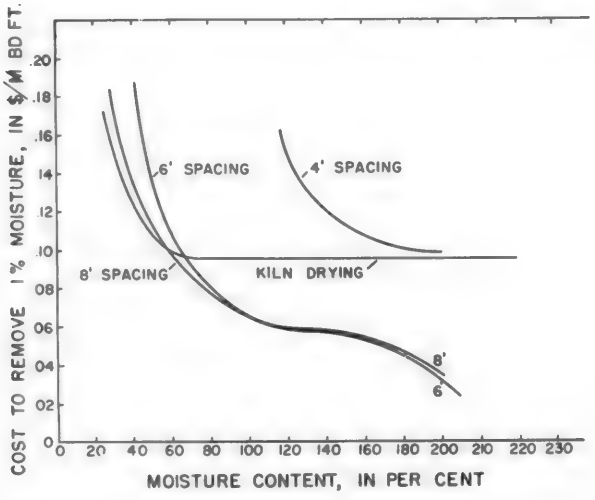


Figure 5.—Turnover of 1 in. sinker redwood lumber per acre as a function of spacing between piles and moisture content to which the lumber is air dried.





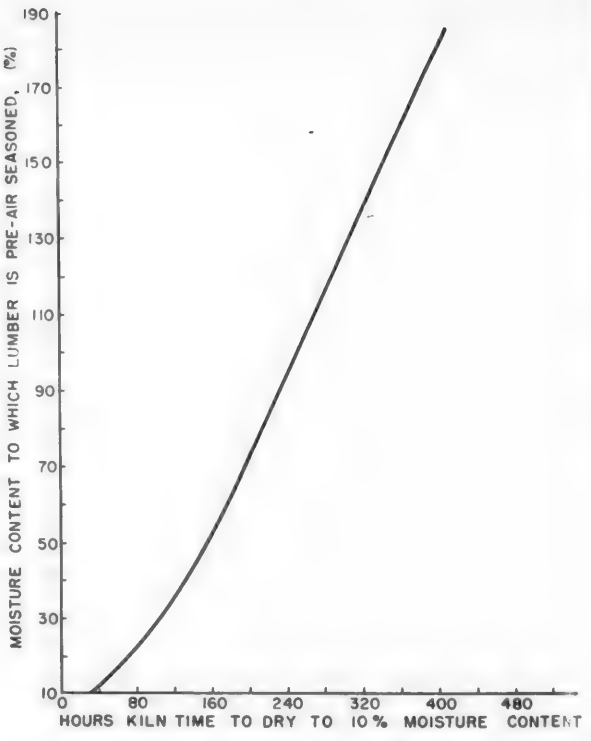


Figure 6.—Curves showing the cost of air drying 1 in. sinker redwood on three pile spacings as a function of the moisture content to which the lumber is air dried. (Above, left)

Figure 7.—Curves showing the cost of removing one per cent moisture from redwood lumber by air drying on three different pile spacings and by kiln drying as a function of the moisture content of the lumber. (Left)

Figure 9.—Curve showing the relationship between the time required to kiln dry redwood lumber to 10 per cent moisture content and the moisture content of the lumber when placed in the kiln.

Figure 4 shows the effect which pile spacing has on the time required to reduce the slowest drying packages in the 1 in. sinker blocks to various moisture contents. The curves for the wider spacing of the 1 in. sinker of Figure 4 and of the other segregations tested occur below the curves for the narrower spacings. This relationship indicates that the lumber will dry faster on wider spacing. Curves such as shown in Figure 4 were used to determine the time required to dry blocks of lumber to various moisture contents on the various spacings tested.

Another important consideration in planning an air-drying yard is the effect which pile spacing has on volume of lumber dried per acre per year. Turnover per acre per year is particularly important at some plants in which the land available for drying yards is limited. Figure 5 shows graphically the relationship between rate of turnover and moisture content to which the lumber is dried for 1 in. sinker on four, six and eight foot pile spacings. This graph was prepared using time requirements taken from Figure 4.

Turnover of lumber per acre per year dried to any given moisture content increases as the pile spacing is increased from a minimum and reaches a maximum after which, unlike the rate of drying, further increases in pile spacing reduce the rate of turnover. Apparently this relationship results from the following: As the yard is opened at the narrower spacings, the rate of drying increases very rapidly so that even though it is not possible to get as much lumber on each acre of yard, the faster rate of drying is effective enough to result in a net increase in turnover. However, since the increase in drying rate tends to level off with increased spacings beyond a certain point, the effect of less lumber per acre on those spacings beyond that point more than offsets the decreased time required to dry the lumber on the wider spacings. The net effect of wider spacing beyond the critical point is to decrease

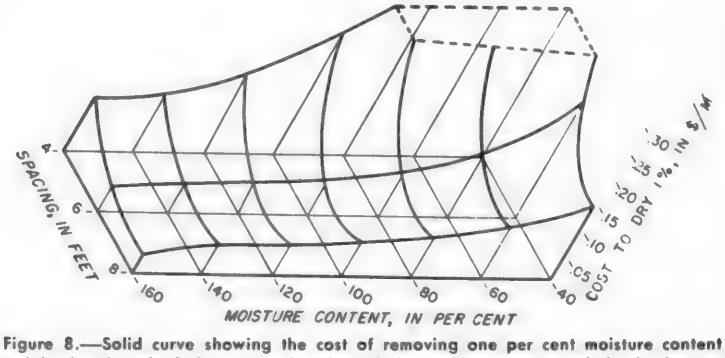


Figure 8.—Solid curve showing the cost of removing one per cent moisture content from redwood lumber by air drying, as a function of the moisture content of the lumber and the spacing between piles in the drying yard.

the annual turnover rate per acre of yard.

For the particular conditions of the tests on 1 in. sinker, the greatest turnover was obtained on six foot spacing. Similar graphs for other segregations indicate that maximum turnover was dependent upon the segregation and thickness as well as on pile spacing. That is, the spacing which gave the best turnover rates for one segregation and thickness did not result in the greatest turnover per acre per year for other segregations. For example, in considering 1¼ in. sinker, it was found that the six foot spacing resulted in the maximum turnover rates. In analyzing the results for the 2 in. light, a spacing of eight feet between piles resulted in the maximum turnover rate.

Drying Cost Analysis

Since for 1 in. sinker both minimum drying time and maximum turnover of lumber per acre per year did not occur at the same pile spacing, it was necessary to evaluate their effects on a cost basis to determine the optimum spacing.

The cost of air seasoning lumber in yards may be broken down into the following elements:

1) Costs based on value of lumber drying:
   - A. Interest
   - B. Taxes
   - C. Insurance
2) Costs based on value of yard including land and improvements:
   - A. Depreciation and Interest
   - B. Taxes

By far the largest part of the cost of air seasoning lumber can be attributed to those costs based on the value of the lumber in the yard. Even at plants in which the yards are paved, depreciation, interest and taxes on the yard itself represent only about one-tenth of the total cost of air drying. Because of this relationship, the problem of minimizing the total cost of air seasoning resolves itself largely into one of minimizing time required to dry the lumber. It has been shown experimentally that improper spacing will restrict the rate of drying of the lumber and that by opening such yards the rate of drying is increased. In increasing the spacing between piles a point is reached, eventually, where increasing the spacing may not decrease costs resulting from decreased time in proportion to the increased cost of the extra yard area required. Since this point is dependent upon the drying climate, it is necessary to evaluate, at each plant, the various spacings which may be near the optimum.

Having determined the cost per day of those items listed above as costs of air drying, the actual cost to dry the lumber can be calculated by multiplying the total cost per thousand board feet per day of keeping the lumber in the yard by the number of days required to dry it from any initial moisture content to any desired final moisture content. The number of days required to dry the lumber may be taken from curves such as those in Figure 4. Cost data and the method of using it for the preparation of air and kiln drying cost curves are shown in Table 1.

Cost of drying 1 in. sinker to various moisture contents using four, six and eight foot spacings in the test yard are shown graphically in Figure 6. The cost to dry each successive one per cent moisture from the lumber at any moisture content can be determined from these curves. Figure 7 is a graph of the data obtained in this manner from the cost curves of Figure 6.

It is apparent from the cost curves that of the three spacings tested, the eight foot spacing resulted in lowest drying costs for the 1 in. sinker. In order to determine the actual spacing which could be expected to give the lowest possible costs, the cost data in the family of curves of Figure 7 was used to prepare Figure 8.

The shape of the solid curve of Figure 8 indicates that a spacing of seven to eight feet would result in the lowest cost for removal of all or any part of the moisture and a spacing greater than eight feet or less than seven feet would increase the cost. The actual minimum cost occurred somewhere between seven and eight feet. It is likely that the same spacing would be optimum for slightly faster summer drying conditions as well as for the conditions under which the test was made.

From Figures 4, 5, and 8, it is apparent that a decision should be made between the 6 and 8 foot spacings for the yard in which the tests were made. The effect of each spacing on the factors which must be considered in making this decision is shown in Table 2. For this analysis the production to be dried was assumed to be in the proportions shown in column B. Values obtained for 1 in. light were used for 1¼ in. light since the latter segregation was not included in the test. It was assumed in the analysis that all of the lumber was to be air dried to a moisture content of 45 per cent.

Summary

The following is a summary of the analysis:

1. Spacing the piles eight feet apart will require .065 acres more per million board feet dried than if they were spaced six feet apart.
2. Spacing the piles eight feet apart will require $780.00 more capital investment per million board feet dried than if they were spaced six feet.
3. Spacing the piles eight feet apart will result in a total drying cost of $745.00 less per million board feet dried per year than if six foot spacing is used.

Because 1 in. sinker usually comprises over half of the lumber in redwood air-seasoning yards, and also since optimum conditions of air drying are nearly the same for all segregations, and since it is practical to select one spacing for the yard, the most economical spacing for the 1 in. sinker should determine the spacing used throughout the entire air drying yard.

Efficient plant operation requires that lumber be dried at as low a cost as possible without degrading. This means that not only must the characteristics of an efficient yard be determined, but in each plant a comparison should be made between the cost of removing the moisture by air and by kiln drying.

The cost of kiln drying lumber may be broken down into the following elements:

1. Costs based on value of lumber being dried.
   - A. Interest
   - B. Taxes
   - C. Insurance
2. Costs based on value of kiln investment.
   - A. Depreciation and Interest
   - B. Taxes
   - C. Insurance
3. Cost of power requirements
4. Cost of degrade from kiln drying
5. Supervision and Labor

Those costs per day of kiln drying which are based on the value of the lumber are equal to the costs per day of air drying based on the value of the lumber. However, unlike yard drying, these costs based on the value of the lumber represent a very small part of the total cost of kiln drying lumber. They probably never exceed five per cent of the cost of kiln drying.

The costs of kiln drying based on the value and operation of the kilns

Table 1—YARD DRYING COST ANALYSIS

LUMBER COSTS

Value of lumber (rough green in yard): $125 per M.b.m.	
Interest	$7.50 per year
Taxes	1.14 per year
Insurance	1.00 per year
Total cost per M.b.m.	$9.64 per year
Total cost per M.b.m.	0.0264 per day

YARD COSTS

Value of yard (land and improvements): $12,000 per acre	
Depreciation and Interest	$1,325 per year
Taxes	240 per year
Total cost per acre	$1,565 per year
Total cost per acre	$ 4.26 per day

COST PER DAY OF YARD DRYING

	Yard Spacing		
	4 ft.	6 ft.	8 ft.
M.b.m. per acre	1,025	875	768
Yard cost per acre per day	$4.26	$4.26	$4.26
Yard cost per M.b.m. per day	$ .00416	$ .00487	$ .00554
Lumber cost per M.b.m. day	$ .02640	$ .02640	$ .02640
Total yard drying costs per M.b.m. per day	$ .03056	$ .03127	$ .03194

Table 2—ANALYSIS OF THE EFFECT OF 6 FT. AND 8 FT. SPACING ON TOTAL AIR DRYING COSTS, AREA AND CAPITAL REQUIREMENTS

Segregation	Production of Each Segregation Per Million Bd. Ft. Dried M.b.m.	Turnover Per Acre Per Year (Fig. 5) M.M.b.m.		Area Required For Each Segregation Per Million Bd. Ft. Total Dried (Col. B. ÷ Col. C) Acres		Cost of Drying (Fig. 6) $ Per M.b.m.		Total Cost of Drying Per Million Bd. Ft. Dried (Col. B. × Col. E) $	
		6′	8′	6′	8′	6′	8′	6′	8′
1 in. Sinker	650	0.92	0.82	.710	.790	9.75	9.25	6,337	6,012
1 in. Light	50	6.20	10.00	.008	.005	2.60	1.10	130	55
1¼ in. Sinker	50	0.95	0.85	.053	.059	12.00	11.20	600	560
1¼ in. Light	50	6.20	10.00	.008	.005	2.60	1.10	130	55
2 in. Light	200	4.40	6.60	.045	.030	2.90	1.75	580	350
Total	1,000			.824	.889			7,777	7,032

Capital cost for yard per million bd. ft. = Area required per million bd. ft. × cost per acre ($12,000) for yard.
For 6′ spacing: .824 × 12,000 = $ 9,888
For 8′ spacing: .889 × 12,000 = $10,668

Table 3—KILN DRYING COST ANALYSIS

COSTS BASED ON KILN INVESTMENT ($218,000)	
Depreciation and Interest	$29,600 per year
Taxes	4,360 per year
Insurance	2,000 per year
Maintenance	7,640 per year
Total	$43,500 per year
Total	119.20 per day
Electric power	24.30 per day
Fuel Oil	44.45 per day
Supervision and labor	20.00 per day
Total kiln costs	$ 207.95 per day
Kiln cost per M.b.m. based on kiln capacity of 216 M.b.m. per charge	$0.962 per day
Lumber cost per M.b.m. (Table 1.)	$0.0264 per day
Total kiln drying cost per M.b.m. per day	$0.9884
Total kiln drying cost per M.b.m. per hour	$0.0412

are analyzed in Table 3 for the same plant at which the drying cost analysis was made.

While redwood can be kiln dried from any green moisture content to a moisture content of 10 per cent with little or no degrade, the cost of drying by the mild schedule required is prohibitive. Consequently, if redwood is to be kiln dried economically, some degrade will result, and the degree of loss will depend upon the moisture content of the lumber at the time it goes into the kiln. The higher the initial moisture content, the greater are the expected losses. The relationship between initial moisture content and losses from degrade for 1 in. sinker redwood has been found to conform to a straight line curve[3] which can be expressed by the following equation:

Degrade (in $) = ((.018) (Initial Moisture Content in %)) — .36

This equation may be used to estimate the degrade losses which will result in kiln drying 1 in. sinker redwood from any initial moisture content.

The total costs of kiln drying 1 in. sinker from various original moisture contents were calculated and the total costs were converted to the cost of drying each successive one per cent moisture from the lumber. A graph of this cost data was superimposed on the similar cost curve for air drying, Figure 7.

It is obvious that wherever the kiln drying curves are below the air drying curves in Figure 7, it costs less to kiln dry and the water should be removed from the lumber in a kiln. It is also apparent from Figure 7 that it would have been less expensive to dry the lumber entirely in a kiln instead of partially drying on the four foot spacing. After the lumber on the six foot spacing dropped below the 65 per cent moisture content level it could be dried for less cost in the kiln. The critical moisture content on the eight foot spacing was at 55 per cent, where the curves intersect, and drying below this moisture content can be done in the kiln for less than on any spacing in the yard.

Conclusions

The narrow pile spacings which have been in common use in redwood air seasoning yards are inefficient whether considered from the standpoint of turnover of lumber per acre per year, time to dry the lumber to any given moisture content, or cost to dry the lumber.

The economic limits of increased pile spacing can be determined for any redwood drying yard. In the test yard in which the study was made, a spacing of between six and eight feet is most economical, but slightly less yard area would be needed for a given annual production with a six foot spacing.

If drying costs are to be held to a minimum, the point at which it becomes more costly to air dry than kiln dry must be determined and observed in the drying process. This point occurred at 55 per cent moisture content in the case of 1 in. sinker which was air dried under the most economical conditions tested.

Considerable unnecessary cost may accrue from the inefficient operation of redwood drying yards.

Discussion

H. J. M. Jorgenson (Jorgenson-Bennett Manufacturing Company): Is the plant located on a large body of water?

Mr. Clausen: Yes, the plant at which the was made is located on Humboldt Bay on the Pacific Ocean.

Mr. Jorgenson: What is the Equilibrium moisture content and how does it vary due to the change in season?

Mr. Clausen: Along the coast it is approximately 20% with practically no variation during the year.

Robert W. Wellwood (University of British Columbia): Do you experience any Collapse in air drying?

Mr. Clausen: A small amount of collapse sometimes results from air seasoning at those redwood mills located inland from the ocean. The amount is very little.

[3] Pratt, Willard E. 1951 Drying Cost Study. California Redwood Association Research Report Index No. 3.20300, Interim Report A.

Kiln Drying Water and Swamp Tupelo

JOHN M. McMILLEN

Technologist,[1] Forest Products Laboratory,[2] Forest Service, U. S. Department of Agriculture

Describes tests run to determine proper kiln schedules for drying of sap and heartwood of swamp and water tupelo. Schedules determined as practical are given. Various separations by species and by sap and heartwood are suggested for best results. Control of warping and case-hardening-relief and final moisture content are also discussed.

Introduction

AMONG THE MORE common trees of the South are the tupelos. The name "tupelo" includes four species of the genus *Nyssa*: namely *Nyssa sylvatica,* black tupelo; *N. sylvatica* var. *biflora,* swamp tupelo; *N. aquatica,* water tupelo; and *N. ogeche,* ogeechee tupelo. The lumber from the black tupelo is commonly called blackgum, and that from water tupelo is called simply tupelo. The lumber from the swamp and ogeechee tupelos may be mixed in with that from either of the other species because there is no way of distinguishing the species by wood structure or general lumber characteristics.

Black tupelo grows in most of the territory east of the Mississippi and southwest to central Texas. In the North it occurs in wet locations as well as on high ground, but in the South it is generally restricted to relatively well-drained sites. The other species grow in fresh-water swamps and along the edges of streams and ponds in the South and Southeast. Water tupelo is the most prevalent and grows in a belt about 100 miles wide along the Atlantic coast from Virginia to northern Florida, westward through the Gulf States to southern Texas, and northward up the Mississippi Valley to southern Illinois. The range of swamp tupelo is approximately the same as that of water tupelo, except that it rarely grows north of Baton Rouge, La. Ogeechee tupelo is rare and of little commercial importance.

Blackgum lumber has long been used commercially, and its seasoning characteristics are well known. Specific kiln schedules were reported by Torgeson,[4] and standard kiln schedules T12-E5 and T11-D3 are listed for the 4/4 to 6/4 and 8/4 lumber, respec-

[1] Experimental kiln runs made by collaborators Ole Karlsen, Institute of Woodworking and Wood Technology, Oslo, Norway, and Sixto J. Pericchi, University de Los Andes, Merida, Venezuela, under the direction of the author.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[4] Accelerated Type of Kiln-Drying Schedules for 1- and 2-inch Blackgum. O. W. Torgeson. South. Lbrmn. Dec. 15, 1946.

ABOUT THE AUTHOR: McMILLEN, JOHN M. Has conducted research in the field of seasoning including chemical seasoning, special seasoning methods, kiln-schedule development and analysis of internal stresses in wood during drying. Received BS degree in forestry in '33 and MS in '38 from the University of Minnesota. Early experience included general forestry the Superior National Forest, FPL logging and milling studies in the Southeast and seasoning and preservative treatment of cross ties and poles and development of water repellents and end coatings in the wood preserving industry. Joined the staff of the FPL in '42.

Figure 1.—Water tupelo (*Nyssa aquatica*) growing in typical site in Louisiana.

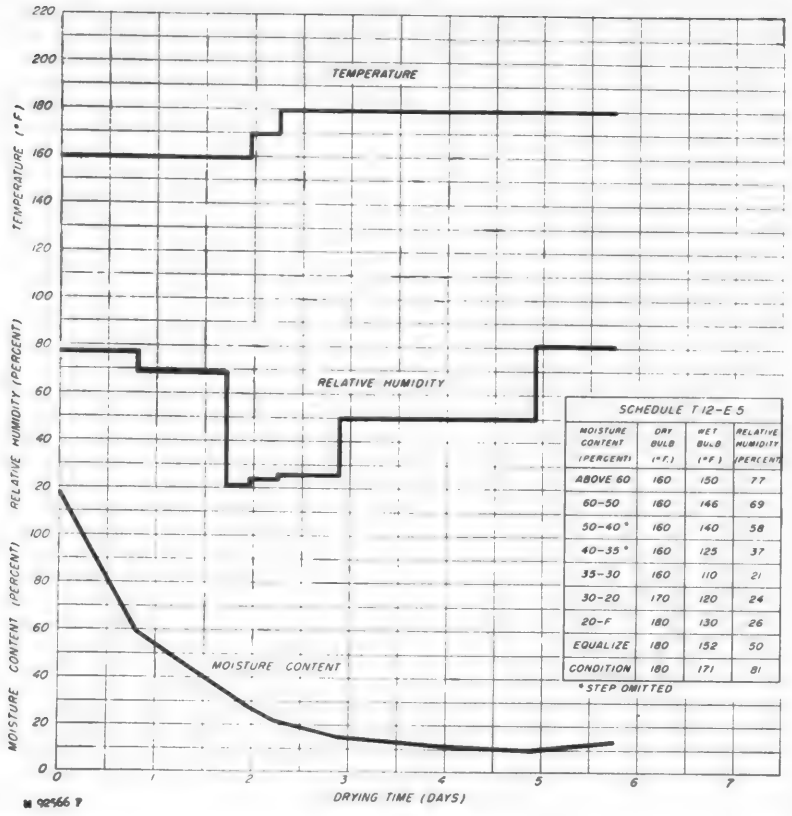


Figure 2.—Kiln conditions and drying curve for 1-inch sapwood of water tupelo and swamp tupelo dried together using schedule T12-E5.

tively, in the Forest Products Laboratory report, No. D1791,[5] on its new schedules for the kiln drying of wood.

Until comparatively recent times, the lowland species of tupelo were bypassed as of low value. Lately, however, commercial interest has increased in water tupelo, and the lumber has appeared on the market under the name "tupelo," or sometimes as "bay poplar."

At the time of publication of Report No. D1791, satisfactory data were lacking on kiln schedules for water tupelo; so it was assigned the same schedules as blackgum. Information reached the Laboratory, however, that these schedules were not always satisfactory and that difficulties were encountered in drying water tupelo heartwood by any schedule without excessive degrade. As a part of its program of research, the Forest Products Laboratory decided to obtain a considerable quantity of water tupelo and determine which of the schedules listed in Report No. D1791 are most suitable for it.

Discussion with members of the staff of the Southern Forest Experiment Station, New Orleans, La., brought out that swamp tupelo or swamp blackgum (*N. sylvatica* var. *biflora*) grows quite generally in association with water tupelo; so the study was extended to this species. Because of the necessity of distinguishing between these two species, the terms "water tupelo" and "swamp tupelo," instead of the simple term "tupelo," are used for the lumber throughout this report. A photograph of water tupelo is shown in figure 1.

The sizes covered by this report are 4/4 and 6/4 lumber.

Material and Experimental Procedure

The material consisted of eight 16-foot water tupelo logs ranging from 18 to 28 inches and seven 16-foot swamp tupelo logs ranging from 16 to 25 inches in diameter inside the bark at top end. It came from the vicinity of Pontchatula, La., and was donated by Mississippi Products, Inc., Jackson, Miss. The logs were generally classified as good sawlog and veneer grade. No low-density swollen butts were included. An 8-foot length of five logs from each of the two species was used as material for veneer-cutting studies reported elsewhere.[6]

Soon after the logs were received at the Laboratory, a variety of items proposed for study were marked out on the end of each log. Those in the dark-colored central portion were designated as heartwood, and those in the lighter outer zone as sapwood. The items were sawed out according to the marking in considerably oversize boards, which were then stored in the green condition at a temperature of 35° F. Immediately prior to each series of experiments, the material needed was rough-dressed to the slightly oversize dimension common to green hardwood lumber.

The dressed boards were cut into short specimens 28 inches long, using the general procedures described in Forest Products Laboratory Report No. R1607.[7] There was considerable variation in the green moisture content of individual specimens. Water tupelo varied from 102 to 184 percent for heartwood and 80 to 163 percent for sapwood. Swamp tupelo varied from 63 to 140 percent for heartwood and 84 to 135 percent for sapwood. Average specific gravities were 0.42 for water tupelo and 0.48 for swamp tupelo.

For the purpose of the experiments, one end of each specimen was end coated to help the specimen approximate the drying rate of full-length material, while the other end was left uncoated to show the effect of the kiln conditions on the control of end checking.

Fourteen kiln runs were made in all, the first ones attempting to check the suitability of the blackgum schedules for these woods, the others attempting to apply various principles of acceleration to speed up the drying after it was discovered that milder initial conditions were necessary for the water and swamp tupelos. The schedules and drying times for the different items are shown in table 1. Since it was found that there was a very great difference in drying characteristics of the sapwood and the heartwood of both species and that the swamp tupelo or swamp blackgum withstood more severe schedules than the water tupelo and dried faster, the separate items are arranged in the table and in the text in progressive order from the easiest to the hardest drying job. Also, wherever a numbered schedule, such as T12-E5, is shown, it refers to the standard schedules published in Forest Products Laboratory Report No. D1791.[5]

Results With 4/4 Lumber

Sapwood, Both Species: The first run was made on the sapwood of both species, using the schedule given for blackgum, T12-E5. This schedule

[5] Schedules for the Kiln Drying of Wood. O. W. Torgeson. U. S. Forest Products Laboratory Report No. D1791. Feb. 1951.

[6] The Rotary Veneer Cutting and Drying Properties of Tupelo. John Lutz. Unpublished report of U. S. Forest Products Laboratory.

[7] Use of Kiln Samples in Operating a Lumber Dry Kiln. H. H. Smith. U. S. Forest Products Laboratory Report No. R1607. 1948.

proved to be generally satisfactory. There was very little surface checking, associated with defects in the wood. End-check penetration was limited to 2 inches. In this thickness, the wettest swamp tupelo did not dry much faster than the water tupelo. The total kiln time, including 2 days of equalization and ¾ day of conditioning, was 5¾ days. The kiln schedule, the kiln conditions actually used, and the drying curve of the wettest half of the kiln samples of both species are shown in figure 2. The actual kiln conditions departed from the kiln schedule for two reasons. First, the drying rate was so fast that steps Nos. 3 and 4 of the schedule were bypassed. Second, equalization had to be started at the end of 3 days of drying because the driest samples were down to the minimum moisture content value, while the average moisture content of the wettest samples was still comparatively high. The swamp tupelo probably could have been dried by itself in 4 days, but segregation may not be practical for 4/4 stock. The final average moisture content in this run was high because of the slow drying of the wetter samples during equalization. In later runs equalization was not started until "wild" kiln samples that seemed to dry at an unusually fast rate had dried to 2 or 3 percent below the set minimum moisture content value, and in some runs the equalizing E. M. C.[5] was set 1 percent lower than the standard recommendations.

Heartwood, Water Tupelo: The first run on 4/4 heartwood included both the water and the swamp tupelo and followed schedule T12-E5. Both species end checked excessively and honeycombed under these severe conditions. As an expedient, both species were dried together again with a schedule derived from a sweetgum heartwood schedule, as far as temperature and humidity numbers were concerned.[5] The humidity letter was modified so as to allow for the extremely high moisture content of the tupelos in the green condition. The resultant schedule was T8-F4. The kiln schedule, actual kiln conditions, and the drying curve of the wettest half of the water tupelo specimens are shown in figure 3. The moisture content values of these water tupelo specimens at the time kiln changes were made were higher than the schedule called for because actual operation was based on specimens of both species.

Figure 3 also indicates the extremely fast drying rate of sapwood included in the run. It shows the disadvantage of including sapwood in a heartwood kiln charge because of the necessity

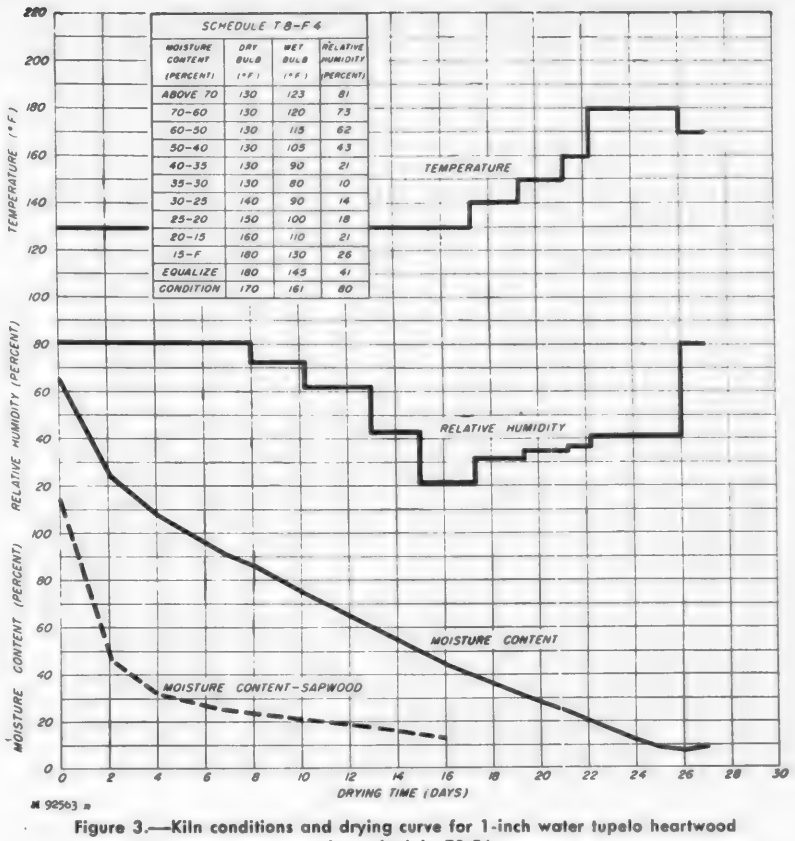


Figure 3.—Kiln conditions and drying curve for 1-inch water tupelo heartwood using schedule T8-F4.

of starting the equalizing while the charge still is at the lower temperatures. This probably increased drying time 2 days or more.

The water tupelo heartwood showed a slight amount of surface checking and end checking with penetrations up to 6 inches. Also, the slowest-drying specimen showed very slight honeycombing. It is believed that drying defects would not have been excessive if temperature changes had not been made until the moisture content was down to 30 percent.

Heartwood, Swamp Tupelo: In the matter of seasoning defects, the schedule shown in figure 3 was entirely satisfactory for swamp tupelo. It showed only minor end checks, surface checks in defective areas, and maximum penetration of end checks of 1½ inches. Subsequent research, however, showed that the 6/4 could be dried by a more severe kiln schedule, so the more severe schedule is also recommended for the 4/4.

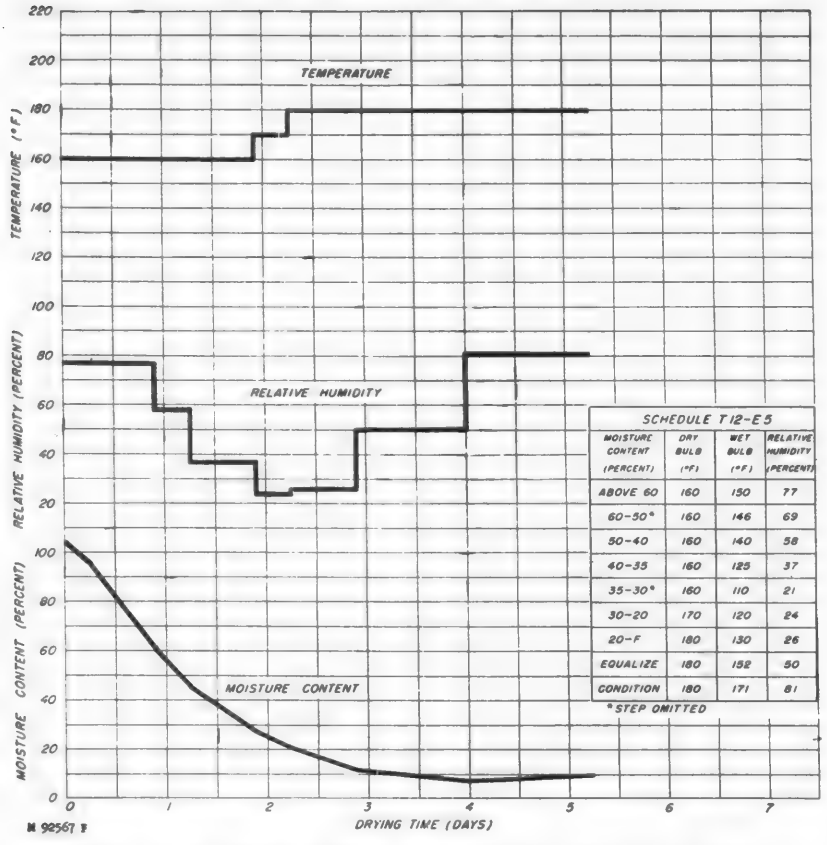
Results With 6/4 Lumber

Because of the results obtained with the 4/4 stock, all experimental runs on the 6/4 stock were separate as to sapwood and heartwood, also species.

Sapwood, Swamp Tupelo: The most satisfactory kiln schedule for 6/4 swamp tupelo sapwood is shown in figure 4, along with the actual kiln conditions and the drying curve of the wettest samples. The schedule, T12-E5, is the same as the schedule for 4/4 sapwood. Drying time was 5¼ days. This is slightly less than the drying time for the 4/4 stock, but, in the run illustrated in figure 2, the drying of swamp tupelo was delayed because of the water tupelo in the run. In the 6/4 run shown in figure 4, the swamp tupelo was down to about 12 percent moisture content and able to stand a temperature of 180° F. when equalization was started at the end of 3 days. One day of equalization followed by 1¼ days of conditioning resulted in a final moisture content of approximately 10 percent.

When another run was made at a slightly less severe schedule, T11-E5, equally satisfactory results were obtained except that drying time was longer, 6¾ days.

Sapwood, Water Tupelo: The most satisfactory kiln schedule for 6/4 water tupelo sapwood was T10-F4. This schedule, along with the actual kiln conditions and drying curve, are shown in figure 5. Drying time was 10¼ days, approximately twice as long as the drying time, with the slightly more severe schedule for the swamp tupelo sapwood in this size. The run



SCHEDULE T12-E5

MOISTURE CONTENT (PERCENT)	DRY BULB (°F)	WET BULB (°F)	RELATIVE HUMIDITY (PERCENT)
ABOVE 60	160	150	77
60-50*	160	146	69
50-40	160	140	58
40-35	160	125	37
35-30*	160	110	21
30-20	170	120	24
20-F	180	130	26
EQUALIZE	180	152	50
CONDITION	180	171	81

*STEP OMITTED

Figure 4.—Kiln conditions and drying curve for 1½-inch swamp tupelo sapwood using schedule T12-E5.

was entirely satisfactory for the material that was really sapwood. Maximum end-check penetration was about 2½ inches. When the green specimens had been prepared, however, some of the outer heartwood, which had the same general appearance as the sapwood on the end of the log, was included as sapwood. The drying curve of this type of material is shown by the dotted line in figure 5. In view of the fact that changes in kiln conditions were made when these specimens were still at a high moisture content, considerable damage was done to the wood. It end checked and honeycombed severely.

In another kiln run, use of the somewhat more severe T11-F5 schedule on water tupelo sapwood gave unsatisfactory results. There was extensive honeycombing in two of the five pieces.

Heartwood, Swamp Tupelo: The most satisfactory kiln schedule for swamp tupelo heartwood in 6/4 thickness was the T10-E3 schedule. The schedule, the actual kiln conditions, and the drying curve for this stock are shown in figure 6. Drying time, 40 days, was considerably longer than the 5¼ days for the sapwood of the same species and thickness. This is partly due to schedule difference and partly due to difference in innate drying rate. Drying results were generally satisfactory, end-check penetration going to 2¼ inches on most of the specimens as a maximum. An intermediate moisture content test was made on one of the wet samples at 45 percent moisture content. At this time the temperature was changed to 150° F., and the sample was put back in the kiln without being end coated. Internal tension stresses were at a maximum at this point, and the wood was wet in the core. It was thus especially subject to end checking, and an end check later opened up into a bad honeycomb check. Such end checking and honeycombing should not be expected if changes in temperature were not made until the very wettest sample was not more than 5 percent above the average moisture content of the wettest half of the stock, which average is usually used as a basis for changing kiln conditions.

Another run was made with this item, using the T8-F4 schedule found satisfactory for 4/4 water tupelo heartwood. The run was generally satisfactory as to seasoning defects, but the drying time was considerably longer, 47 days in comparison with 41 days. This is a strong indication that the T10-E3 schedule should be used for 4/4 swamp tupelo to save drying time.

Previous research[6] with sweetgum heartwood showed that a very rapid lowering of relative humidity could be made after the stage of maximum tension stresses in the exterior zones of the wood had been passed. One experimental run was made with 6/4 swamp tupelo heartwood to try out this type of schedule, using 130° F. and a 7° wet-bulb depression as the initial conditions. The first relative humidity drop was made when the moisture content had been reduced to about 0.6 of the original. The pattern of the No. 4 humidity schedules[5] was used to increase the wet-bulb depression, but one change in humidity was made each day regardless of moisture content. Surface checking was entirely absent, and end checking only slight to moderate under initial conditions. No surface checking occurred as a result of the rapid relative humidity drop, but it did cause end checks to lengthen and to develop into honeycombing. In one of the wettest specimens the honeycombing penetrated 14 inches from the end. It thus appears that, for the time being at least, it will not be practical to use a schedule with an extremely rapid relative humidity drop for the heartwood of even this more easily dried swamp tupelo species.

Heartwood, Water Tupelo:—No kiln schedule tried was found entirely satisfactory for 6/4 water tupelo heartwood. The first experiment was the same as the method described above for swamp tupelo, in which initial conditions of 130° F. and 7° F. wet-bulb depression were followed by a rapid humidity drop after approximately one-third of the original moisture content had been removed. This caused bad end checking and honeycombing and was considered entirely unsatisfactory.

The next schedule used was the T8 temperature schedule in combination with one of a newly-designated series of humidity schedules which are called the *H* schedules. These schedules have the same pattern of wet-bulb depressions as the standard Forest Products Laboratory schedules described by Torgeson,[5] but the first drop in relative humidity is made when one-third of the total green moisture content of the wood has been evaporated and subsequent drops are made at 10 percent moisture content intervals until the minimum practical wet-bulb temperature is reached. This principle is not new, in fact it was used by many of the investigators

[6] Accelerating the Kiln Drying of Hardwoods. R. C. Rietz. South. Lbrmn. 181(2262):43–44, 54. July 1, 1950.

whose research was used as the basis of the standard Forest Products Laboratory schedules. The standard schedules themselves follow this principle generally, but for the purpose of standardization, the humidity schedules have been grouped into six series, with the first change in relative humidity for the highest (F) series made at 70 percent moisture content.

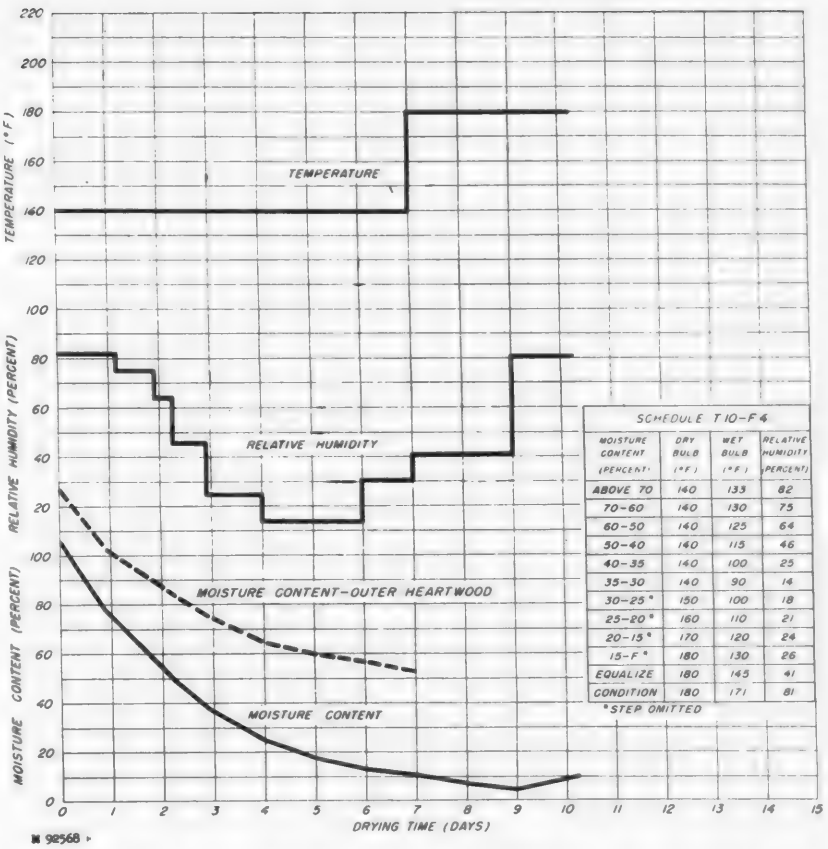
Since the earlier kiln runs had indicated that initial control of drying defects could be achieved by use of a 5° F. wet-bulb depression, the schedule tried was T8-H3. The original moisture content was 168 percent, and two-thirds of that is approximately 110 percent. Results with this schedule were slight to moderate surface checking, moderate end checking, and excessive honeycombing. Since control of honeycombing depends mainly on temperature, and since satisfactory results were obtained with 4/4 water tupelo heartwood at 130° F., it is believed that 120° F. with a proper humidity schedule would be safe for the 6/4 stock. Accordingly, a suggested kiln schedule for 6/4 water tupelo heartwood, T6-H2, is shown in figure 7. The author has no information that this schedule will be entirely satisfactory, but he believes that it would be the most practical if such stock must be kiln dried green from the saw. Drying time is estimated to be in the neighborhood of 60 days.

The drying time with the T8-H3 schedule was about 50 days. A slightly more severe schedule, T10-F3, was tried with this stock and found to be completely unsatisfactory.

General Discussion of Drying

The preceding results indicate quite clearly the desirability of segregating the two species, water tupelo and swamp tupelo, also the sapwood and heartwood within each species. The only sure way to segregate for species is in the tree, using flowers, fruits, or leaves. In some cases the bark may be helpful. Water tupelo bark is usually thinner. In other cases, especially where the two trees are growing in the same habitat, their bark is practically identical. Water tupelo more generally comes from flat flooded lands, and swamp tupelo from the edges of ponds and streams. Just knowing the appearance of the logs from different habitats may make it possible to separate the species at the landing.

If segregation is not made, a large number of kiln samples (10 or 12) should be prepared for each kiln charge, and a water tupelo schedule should be used. As drying progresses, changes in kiln conditions should be based on the average moisture content of the wettest one-fourth of the samples rather than the wettest one-half as ordinarily recommended in Report No. D1791. All the samples would not have to be weighed each time the drying is checked, but the driest sample should be observed regularly to know when to start equalization.



SCHEDULE T10-F4

MOISTURE CONTENT (PERCENT)	DRY BULB (°F.)	WET BULB (°F.)	RELATIVE HUMIDITY (PERCENT)
ABOVE 70	140	133	82
70-60	140	130	75
60-50	140	125	64
50-40	140	115	46
40-35	140	100	25
35-30	140	90	14
30-25*	150	100	18
25-20*	160	110	21
20-15*	170	120	24
15-F*	180	130	26
EQUALIZE	180	145	41
CONDITION	180	171	81

*STEP OMITTED

Figure 5.—Kiln conditions and drying curve for 1½-inch water tupelo sapwood using schedule T10-F4. (Drying curve of outer heartwood shown by dotted line.)

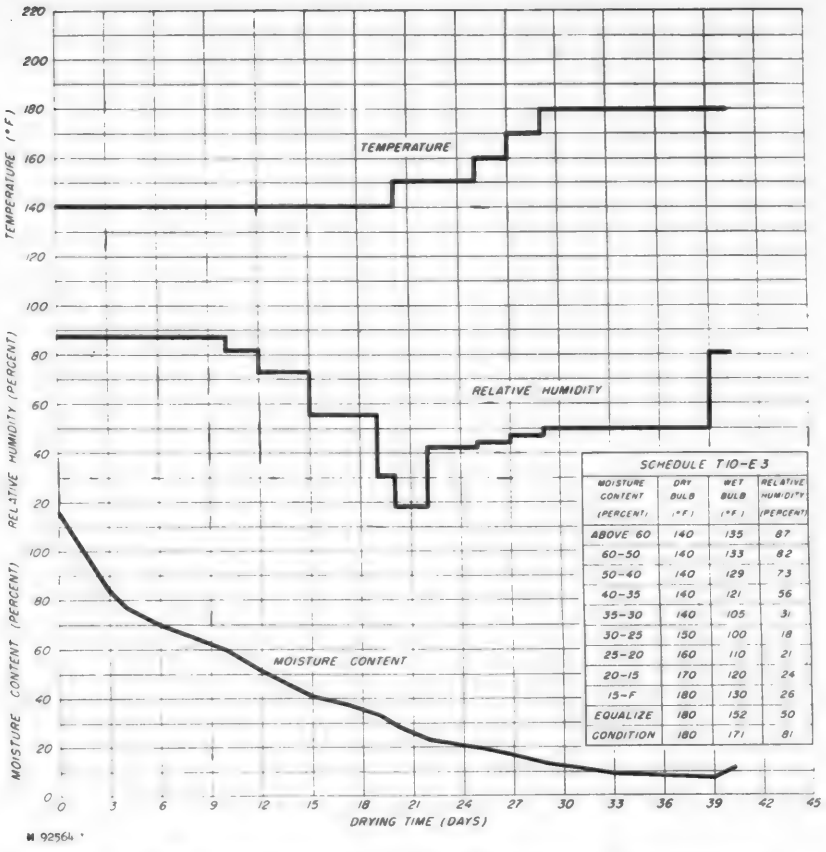
The problem of segregating the sapwood of water tupelo from its heartwood is complicated by the outer heartwood not showing the color of heartwood. It has all the low moisture permeability characteristics of true heartwood. Figure 8 illustrates the condition observed in three specimens of 6/4 water tupelo when cut for intermediate moisture content determinations. Average moisture-content values varied from 26 to 64 percent. When these specimens were in the green condition, they appeared to be 100 percent sapwood. On the intermediate moisture sections, however, there appeared to be a very definite demarcation line between outer, uncolored heartwood and true sapwood. Also, the distance of the inner wet zone from the sapwood-heartwood line in the interior of the piece was approximately the same as the distance between the wet zone and the outer surface in the heartwood portion.

If outer heartwood is included in a charge of sapwood, the use of low humidities and high temperatures must be held up until the heartwood material is down to proper moisture-content values. Otherwise, it would end check and honeycomb badly. The only practical way to avoid getting it

Table 1—KILN SCHEDULES AND DRYING TIMES FOR 1- AND 1½-INCH WATER AND SWAMP TUPELO SAPWOOD AND HEARTWOOD

Class of wood	Species of tupelo	Schedule	Drying time Days
1-Inch			
Sapwood	Both	T12-E5	5¾
Heartwood	Water	T8-F4	27
1½-Inch			
Sapwood	Swamp	T12-E5	5¼
	Water	T10-F4	10¼
Heartwood	Swamp	T10-E3	40½
	Water[1]	T6-H2	60

[1]Suggested kiln schedule and estimated drying time based on nearly satisfactory results with schedule T8-H3.



SCHEDULE T10-E3

MOISTURE CONTENT (PERCENT)	DRY BULB (°F)	WET BULB (°F)	RELATIVE HUMIDITY (PERCENT)
ABOVE 60	140	135	87
60-50	140	133	82
50-40	140	129	73
40-35	140	121	56
35-30	140	105	31
30-25	150	100	18
25-20	160	110	21
20-15	170	120	24
15-F	180	130	26
EQUALIZE	180	152	50
CONDITION	180	171	81

Figure 6.—Kiln conditions and drying curve for 1 ½-inch swamp tupelo heartwood using schedule T10-E3.

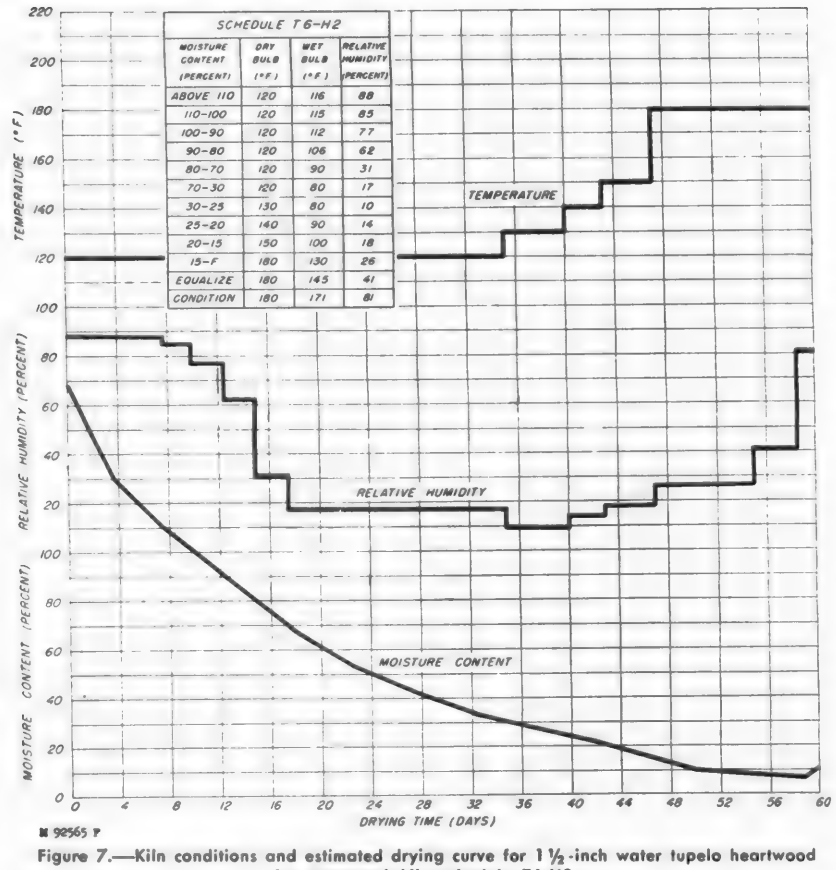

SCHEDULE T6-H2
MOISTURE CONTENT (PERCENT) | DRY BULB (°F) | WET BULB (°F) | RELATIVE HUMIDITY (PERCENT)
ABOVE 110 | 120 | 116 | 88
110-100 | 120 | 115 | 85
100-90 | 120 | 112 | 77
90-80 | 120 | 106 | 62
80-70 | 120 | 90 | 31
70-30 | 120 | 80 | 17
30-25 | 130 | 80 | 10
25-20 | 140 | 90 | 14
20-15 | 150 | 100 | 18
15-F | 180 | 130 | 26
EQUALIZE | 180 | 145 | 41
CONDITION | 180 | 171 | 81
TEMPERATURE (°F)
RELATIVE HUMIDITY (PERCENT)
MOISTURE CONTENT (PERCENT)
TEMPERATURE
RELATIVE HUMIDITY
MOISTURE CONTENT
DRYING TIME (DAYS)
M 92565 F

Figure 7.—Kiln conditions and estimated drying curve for 1 ½-inch water tupelo heartwood for suggested kiln schedule T6-H2.

mixed in with the sapwood would be for the sawyer to take off only a small amount around the log as sapwood. The rest, as it comes off the saw onto the green chain, should be marked as heartwood, and it should be dried as such.

The uncolored heartwood problem did not exhibit itself in the case of the swamp tupelo.

Control of Warping

Because of the presence of interlocked grain in the tupelos, warping is a considerable factor in their drying. All forms of warp occur: cup, bow, crook, and twist. A minor study of the effect of various kiln schedules on warping was carried out in the drying of the 4/4 material. The object of this study was to find out if there were any differences inherent to the schedules themselves that would result in less warping. General research on the stresses in wood as it dries and on shrinkage of wood indicates that more "set" occurs when lower temperatures and low humidities are used in comparison with higher temperatures and higher humidities. If "set" can be established during the period when the lumber is comparatively green and straight, it should be a deterring factor to warping. The kiln conditions used in this experiment were the initial run of high temperature and high humidity T12-E5, the satisfactory run T8-F4, and a moderately low-temperature, low-humidity schedule T4-E6. In order to eliminate the factor of weighting, a uniform weight of approximately 15 pounds per square foot was used on all piles. The piles themselves were five layers high, so the warping expected would be about average for the upper third of a kiln truckload of lumber. That is where the major difficulty from warping occurs.

In general, there were no differences in the amount of warping as a result of the differences in kiln schedule. This is in accord with previous general findings on the effect of kiln schedules on warping. There is no practical advantage in using a low temperature if warp control is the object. Drying time with the low-temperature, low-humidity run was slightly longer, 29 days in place of 27. Drying defects were generally not serious under this schedule, however. As indicated by Torgeson,[9] weighting of the kiln load to 90 pounds per square foot or more could be expected to give considerably greater control of warp. It may be necessary or desir-

[9] Does Weighting of Kiln Loads Reduce Warping in Kiln Drying of Hardwoods? O. W. Torgeson. U. S. Forest Products Laboratory Report No. D1769-14. Wood and Wood Products. Apr. 1952.

able to use a means of clamping down the load with irons fastened either by strong springs or by take-up devices instead of weights. Whether the use of a low-temperature, low-humidity schedule in combination with weighting or clamping would be helpful has not been determined.

Case-hardening Relief and Final Moisture Content

In all cases the general procedure for equalization and conditioning as given in Report No. D1791 was followed. Good relief of case-hardening was generally attained. Some modification of the procedure was necessary because of the extremely variable drying rate of the different items of tupelo with the consequent result in different final moisture content values and the need for long equalization treatments. The E. M. C. conditions used during the conditioning were generally such as to give a final desired average moisture content of 8 percent, that is, about 11½ percent E. M. C. Because one end of each specimen was not end coated, the average moisture content went down below the moisture content that a fully end-coated kiln sample would go to under the same conditions. As a general procedure, a 6 percent E. M. C. condition was used when the driest specimens got down to 5 percent or less. Even under these conditions, many of the specimens continued to dry until their indicated moisture content, based on the calculated oven-dry weight, was in the neighborhood of 2 percent. Average moisture content values of the wetter specimens were in most cases brought to 7½ to 8 percent or lower. Because of the slow drying rate of many of the higher moisture content specimens under the 6 percent E. M. C. condition of equalizing, in some of the runs a 5 percent E. M. C. condition was used. The 5 percent E. M. C. condition resulted in a little faster drying of the wettest specimens and did not dry the driest specimens so low as to give reverse case-hardening. Generally good relief of case-hardening was attained, except that the exceptionally high moisture content specimens still came out with case-hardening.

Moisture pick-up was rather high, 3 to 4 percent. As a result of this, the final moisture content of sections cut from the middle of the specimens ranged from about 9 percent to 10.4 percent in the 6/4, although they came out closer to 8 percent in the 4/4. For wood like tupelo, control of moisture regain perhaps could be obtained by using a shorter conditioning time with the same E. M. C. conditions. It would also seem desirable to dry the wettest samples down to 7 percent instead of 8 percent, as called for by the standard procedure. While 9 percent might be a satisfactory final moisture content for stock to be made into furniture for use in the South, if such stock is to be used in the North, a lower final moisture content is desirable. For the time being, it is suggested that the moisture content of the driest sample before equalization and the E. M. C. of equalization be 1 percent lower than the values called for in table 2 of Report No. D1791 for any final desired average moisture content. The E. M. C. for conditioning should be the same as the table calls for.

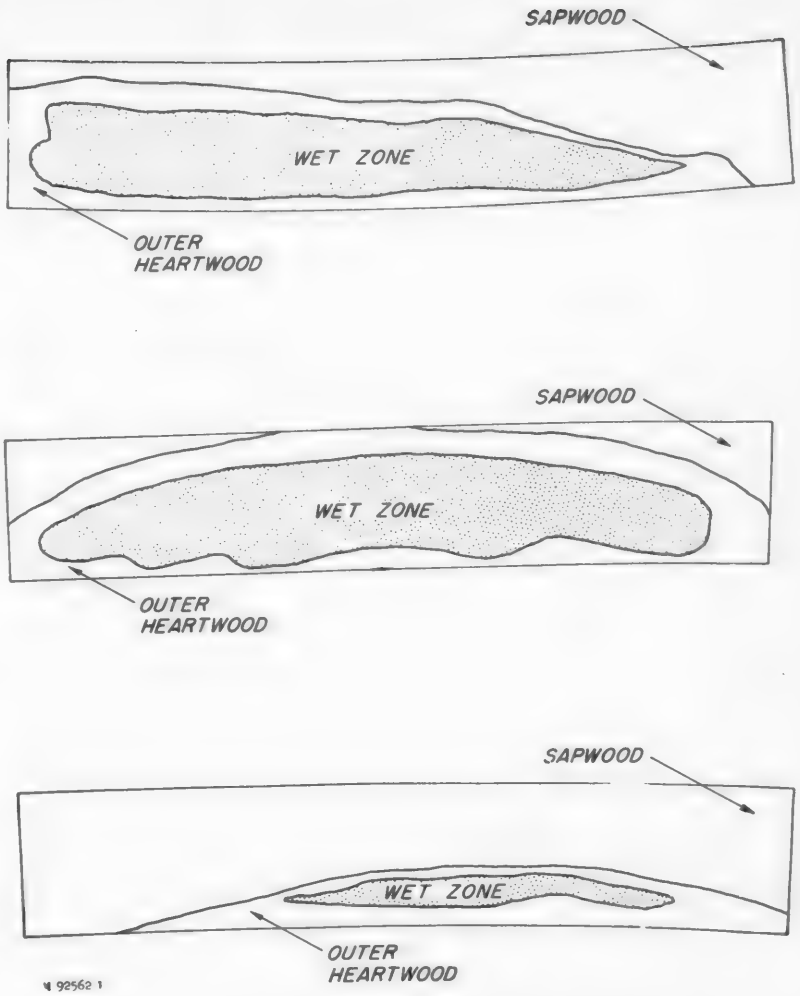


Figure 8.—Cross sections of water tupelo in which all the wood had the appearance of sapwood when green but a definite zone, called outer heartwood, had the drying characteristics of heartwood.

Discussion

George C. Lucas (May Brothers): I noted that your schedule for 4/4 water tupelo heartwood required 27 days drying time. We have been using a schedule worked out by ourselves that successfully dried 4/4 tupelo heartwood in 14 to 16 days. I do not recall the details of the schedule. Also, I am not sure what kind of tupelo it was. Your work shows that swamp tupelo dries faster than water tupelo.

Mr. McMillen: Although I do not know for sure, I believe that the tupelo you dried at your plant in southern Louisiana would most likely be the water tupelo, *Nyssa aquatica*. I have no explanation as to why you were able to dry 4/4 stock in 14–16 days whereas we required 27 days. It may be that the stock you dried was partially air dried when it went into the kiln. Otherwise the kiln conditions required for such fast drying would probably cause honeycombing. We would be glad to have you send us more complete data on your experience with tupelo.

Chairman Carter: I would like to suggest that Mr. Lucas send in a copy of his schedule to be included as a part of this discussion.

Mr. Lucas: I am sorry that I am not able to supply records on 4/4 tupelo.

Our drying of this thickness took place over a year ago, and the records have been discarded. We are, however, drying ¾-inch tupelo in about 12 days and ⅝-inch in about 8 days. Some actual drying data are given below.

We do not separate heartwood and sapwood. Drying is partially run on a time basis, but we use a number of samples from a 100 percent heartwood board during each run. One sample 14 to 18 inches long is end-coated and used as a "weigh" sample. The others, uncoated, are distributed throughout the kiln and wafers are cut from one of these each time the "weigh" sample is weighed. Differences in original moisture content along the length of the board partly account for some of the differences shown in the data. While our sampling procedure and control of the kiln are not as close as you would use in experimental work, we do calibrate our instruments periodically and our procedure is sufficiently accurate for us to produce a good high-quality kiln-dried lumber, and it is not honeycombed.

Mr. McMillen: The above would appear to be optimum schedules for ¾ and ⅝ tupelo. Mathematical calculations indicate that 4/4 should take about 1¾ as long to dry as ¾. Dividing 27 days by 1¾ indicates that the T8–F4 schedule would dry ¾ in 15 days. As the thickness of the stock decreases, the lumber will withstand more severe kiln schedules, largely because the stresses are smaller and the time of exposure to higher temperature is shorter. I know that we would have experienced honeycombing with the 4/4 water tupelo material we dried if we had used the temperatures that Mr. Lucas found satisfactory for ¾ stock. There is a possibility, of course, that the water tupelo dried by May Brothers had somewhat better seasoning characteristics than material dried in the Laboratory's study.

John Devine (Moore Dry Kiln Company): How do your schedules affect warping and twisting?

Mr. McMillen: This was not extensively studied, but we do not believe that warping is increased by these schedules.

Mr. Devine: Warping, cupping, etc., could be controlled better by producing maximum tension set by using low temperatures and low humidities in early stages of drying than by weighting down, or tying down.

Mr. Lucas: We formerly weighted down our lumber, but have decided that it is not necessary to do so. Some boards at the bottom of the stack will warp in spite of the tremendous weight upon them, while some boards at the top of the stack will remain straight with no weight on them at all.

Mr. McMillen: Theoretically the formation of a quick "set" of considerable magnitude while the lumber is still about full size and in the flat condition should be helpful in reducing warp. Experiments on small specimens at the laboratory showed that use of a low humidity in combination with low temperature gave more "set" than high temperature-high humidity conditions. In several experimental drying tests, however, we found that the amount that humidity could be lowered without surface and end checking and the amount the temperature could be reduced without unduly prolonging drying time were so small that there was no practical advantage in trying to manipulate the schedule to reduce warp. We have placed our major reliance for control of warping on proper stickering and weighting of the loads, as indicated in the text of the paper. Perhaps the new knowledge to be gained by fundamental studies on stresses in wood as it dries will lead us to schedules giving better control of warping, but we don't know enough about this at present.

H. J. M. Jorgenson (Jorgenson-Bennett Manufacturing Company): Good piling practice improves the straightness of the lumber. However, some freak boards will warp in spite of the best drying methods and weighing down.

Mr. McMillen: Would Mr. Jorgenson comment on air drying?

Mr. Jorgenson: Air drying seems to help. We never put moisture back into air dried Tupelo stock.

Mr. McMillen. What is the approximate kiln drying time for Tupelo at 20% moisture content?

W. W. King (Texas Forest Service): Have you made any studies on the effect of sticker spacing on warping and twisting of Tupelo?

Mr. McMillen: Normal sticker spacing of 18 inches or 2 feet seem to give satisfactory control. It is advisable to stay away from excess spacing of 4–6 feet.

Relocatable Housing: Some Early History and a Present-Day Example at Camp Stewart, Georgia

GEORGE W. STANLEY, JR.

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Explanation is given of the need for and the development of demountable type housing, with emphasis on the Unishelter type. Design, shipment and erection problems and solutions are related and explained. The house is of plywood and lumber construction using Unicel method of stressed-skin design.

THE TITLE OF THIS PAPER may raise a question in the mind of the reader. What is relocatable housing?

Admittedly, it is a fairly uncommon term, although it has been in use longer than might be expected. Essentially, relocatable housing is that housing which can be moved and reused at one or more locations with a relatively small expenditure in manpower or materials. It has also been called demountable housing.

In the case of the particular relocatable house this paper will deal with in detail, other fundamental requirements were:

1) The houses must meet the livability and durability standards generally expected of fixed-to-site housing of permanent quality;

2) The houses must conserve critical materials, at least to the extent required by limitation orders by the government;

3) The houses must minimize on-site hours required to install the houses, including site preparation and foundation.

Early History

Actually, relocatable housing goes back a dozen years.

The Tennessee Valley Authority pioneered in the early developments of demountable housing, as it was then called.

The Federal agency's first venture consisted of a half-dozen experimental summer cottages. They were built at Muscle Shoals, Alabama in 1940.

These were shipped in sections to an original site some 60 miles away. To further demonstrate the feasibility of the idea of moving houses by sections, T.V.A. was asked by the Federal Works Administration to build some defense houses in 1941. These were built in an outdoor field and were shipped in sections to individual sites in and around Muscle Shoals.

The average haul was about 41/2 miles. At that time, those houses would probably have qualified for conventional Federal Housing Administration financing then requirements.

The typical two-bedroom houses were shipped in four sections. The three-bedroom units were shipped in five sections. Each section was complete, even to the paint job, before shipment.

The size of the two-bedroom units was approximately 22′ x 30′ and the three-bedroom unit 22′ x 37½′.

The next development was in 1942 and this was the construction of some very small two-section units that were built in the same field and shipped some 300 miles to a site in the Carolina Mountains. These houses were for construction workers. They were left in their original location at Murphy, North Carolina about a year and were then moved to Hiwassee Dam Project for a year and a half and then moved to Fontana.

These units have been moved approximately 300 miles with two relocations. They are still at Fontana, where they now are used for tourist quarters.

At about the same time, T.V.A. built three dormitory units at Muscle Shoals and these have been relocated once.

These dormitories were shipped in 22 sections, complete with cubicles for men in two main wings and three sections of central wash rooms.

Figure 1.—View of three bedroom house at factory.

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Figure 2.—Corner of living room showing picture window.

Figure 3.—Exterior view of prototype house.

The next major T.V.A. development in relocatable housing was in 1942. This was a new type sectional unit that could be built by trailer manufacturers. A firm in Elkhart, Indiana built 100 of these two section, one-bedroom houses for Fontana. These were highly engineered, stressed skin structures, of a size about 15′ x 24′. These were complete and practically finished prior to shipment and the haul was approximately 600 miles.

A short time later, Manhattan Engineering Project borrowed the plans for the one-bedroom house referred to above, as well as plans for two and three bedroom units, which had been drawn by the T.V.A. staff. Incidentally, they borrowed some of T.V.A.'s housing design-engineering staff along with the plans.

The Army awarded contracts to five companies in the midwest to produce 3,000 of these units in jigtime for the Oak Ridge, Tennessee project. They further negotiated for 1,800 more to be built for the Hanford, Washington Plant, of the Atomic Energy Commission.

The Hanford houses were built by an Oregon sawmill operator, who had a prefab subsidiary. The midwest builders included among others, Bruce Flooring, here in Memphis. The longest haul of these units was probably the 700 mile trip from Alma, Michigan to Oakridge.

The Oak Ridge houses, which have been rented to workers for ten years, have recently been sold off for removal as is, where is. It is interesting to note that the average selling prices ran from $800 to $1,200 for the two-bedroom houses, which originally cost $3,000, and in the neighborhood of $1,700 for the three-bedroom units which originally cost $3,700.

About 1944, the British Government became interested in the T.V.A. efforts. Using the two and three-bedroom Muscle Shoals developments of 1941 as a basis, they designed a somewhat similar type of house with one important fundamental change in that aluminum was used as the principal material of construction.

The British Ministry of Supply negotiated for 50,000 units which were built by five British aircraft builders over a two and a half year period. These were all two-bedroom, four-section units and were shipped throughout England and Scotland during 1945 and 1946 as a part of the emergency housing program.

It should be pointed out that these units were not built as demountable houses, but rather because their design permitted the manufacturers to employ mass production methods.

Defense Housing Today

That brings us up to the 1950's and face to face with the special needs and requirements of present-day defense housing. It was plainly the need for adequate defense housing that could be speedily constructed that gave the more recent impetus to relocatable or demountable housing.

It may be broadly stated that defense housing falls into one of three categories. The No. 1 category would be that of construction projects or military staging operations where it is known in advance that the needs will be of limited duration.

Heretofore, at least, this need has been met by trailer-type housing or temporary barracks; the intention being to dispose of the same when the need has ended. In this group, low first-cost is of primary importance because the entire project expense has to be written off in a very short period of time. This type of housing is known to have proved a deterrent in securing the highest type of workers, particularly civilian workers with families, who are not under the jurisdiction of the military and therefore have freedom of employment choice. Since they are accustomed to better housing, they think twice before accepting a job that carries with it an inferior home and a sub-standard set of living conditions even though their work may be vital to our national security.

All the earlier forerunners of relocatable or demountable housing described above were without exception in Category No. 1.

The No. 2 category of defense housing requirements is in the expansion of defense plants and permanent military installations, where it is known in advance that housing requirements will be reasonably stable for a long time. This housing has traditionally been of the conventional fixed-to-site type; as such, it becomes a part of the community and enhances the net worth of the section where it is located.

There is, however, a broad field in which neither the No. 1 nor the No. 2 categories satisfactorily fills the bill. That situation is one wherein defense activities create critical requirements for good family housing, but provide no assurance that the housing need will exist at that location for the long period of time necessary to amortize its costs at a reasonable rate.

Temporary housing has been tried, but has failed to meet the requirements. Communities everywhere have resisted temporary projects and one cannot blame them after our reviewing some of the examples we have all seen at one time or other.

Recognizing the fact that there was a serious gap in types of available housing to meet this last category, the Housing and Home Finance Agency in early 1952 authorized a trial program to determine the feasibility and economics of good relocatable housing as an alternative to the deficient temporary housing in areas where the

Figure 4.—Looking from bedroom one toward bedroom three.

duration of the need was not certain. Thus was created category No. 3.

Those interested in learning the full story of the trial program may obtain same by writing to the Superintendent of Documents, Washington 25, D. C. and enclosing 25¢ for the bulletin, "Relocatable Defense Housing," House and Home Finance Agency, dated June 1952.

From a total of 36 designs submitted, eight houses of widely differing characteristics, though all aimed at a common goal, were built, assembled, disassembled and relocated under the careful observation of military, national, state and municipal housing authorities.

The Unishelter House

The balance of this paper will be taken up with one of these eight types of housing, the house its maker, the Pressed Steel Car Company, terms the Unishelter which has been selected for the project at Camp Stewart, Georgia.

Two hundred fifty-eight houses, both two-bedroom and three-bedroom, are being set up on this site.

At first glance, it might appear that the problems of designing, building, shipping and erecting a relocatable house would be quite similar to those met in prefabricated housing, but such is not the case.

Prefabricated housing, as its name implies, is that type of house which to a greater or lesser degree is prefabricated at a factory, shipped to the site in what might be called a semi knocked-down condition and there erected. The basic fundamental difference between prefab housing and relocatable housing, is that in the type of erection that has been used with the prefab housing, at the site it becomes fixed-to-site housing, and therefore is not adaptable easily for relocation at a later date. It will thus be seen that one of the major problems that had to be solved was to create a type of construction that would provide satisfactory assembly at site, whether it be for a week, or ten years, and yet would allow inexpensive and satisfactory dismantling, reshipping, and reassembling at another point.

On its face, this is not an easy problem and it is a feather in the hats of our wood industry's designers and managements that such a variety of approaches were discovered and tried.

Under our present finance-banking system, there are few, if any, homes, conventional or otherwise, built in the United States wherein some measure of control is not exercised by the Federal Housing and Home Finance Agency or one of the related Federal agencies. While this may not appear to be obvious on the surface, it is nevertheless a fact. For this reason, the opinions of H.H.F.A. as set forth in their established performance standards for conventional fixed-to-site housing, as well as the performance standards evolved for relocatable housing,* were at all times considered as guideposts in planning the demountable house for the Camp Stewart project.

If you were to compare the performance standards for the Camp Stewart relocatable house with the standards of housing construction necessary to meet F.H.A. Financing requirements, you would see how closely we have tried to adapt our relocatable house to meet all the rigid requirements for F.H.A. financing.

Much favorable comment has been received on the livability we have engineered into the Camp Stewart house.

A requisite of the Camp Stewart house was that it should contain sufficient space and facilities to afford provision for living, sleeping, sanitation, meal preparation, dining, storage for clothing and equipment, laundering, recreation and home maintenance functions, and to contain two or three bedrooms for single family occupancy.

Since these houses do not have basements, a utility room containing furnace, hot-water heater, etc., also had to be provided.

In conformance with F.H.A. standards, minimum areas were prescribed for the various living centers. In preparing the actual design layout for the Camp Stewart house, the minimum standards were exceeded wherever possible, consistent with the over-all problems of price and relocatability.

The usual panegyrics of real estate salesmen are applicable to these houses. The bedrooms have cross-ventilation. The bathrooms have full equipment, tub, shower, etc. The kitchen is fitted with an abundance of shelf and working space and cabinets. Plenty of closet space, full 7′ 6″ height in all rooms, picture windows, varied color schemes inside and out, flush panel doors, patio and trellis, 30 or 40 gallon insulated hot-water heater, furnace system with hot-air heating and over-head registers, outlets in all living areas, fully insulated, etc., etc.

The rooms are all of adequate size and conform to F.H.A. requirements, with the living room, for example, being 17′ x 11.3′. A careful study of the plan will show that a great deal of thought has gone into the preparation from the point of view of the housewife as well as the many functional problems involved.

One of the prime requisites of the relocatable house is that it must be capable of being moved or reused at alternative locations with a relatively small expenditure in manpower or material.

In an actual demonstration, the prototype house of the Camp Stewart design was disassembled from site, placed on trucks, moved to a new site one mile away, re-erected with all utilities connected, furniture reinstalled, etc., by a crew of ten men in less than two hours. NBC Television and Pathe News photographed actual sequences of the official preview for screening throughout the country.

One of the principal reasons we were able to set this speed record was due to the fact that the house is constructed of three main sections, each built on the Unicel principle. The stressed-skin monoccoque construction embodied in the Unicel system pioneered by Pressed Steel Car for its Unicel freight car and later its highway trailer, as applied to this house

Figure 5.—View in kitchen—same for two and three bedroom houses.

* H.H.F.A., August 1952.

Figure 6.—Delivery by railroad flatcar.

Figure 7.—Site view showing preset footings.

make the house sections all individually self-supporting, so that they can be mounted on a minimum number of piers or footings. In the protype house, a 40′ x 10′ unit was mounted on five piers. These three units were shipped completely assembled and, therefore, the erection consists of placing the three sections on the footings which have been preset according to templet, bolting together, placing overhanging eaves and trellis, which are shipped inside one of the main units to save space and freight charges, and connecting up the utilities; namely, sewage, water, electricity, and gas, if called for, to the master-lines at the site.

Since these units are completely assembled, the matter of over-all dimensions are of paramount importance. This is so because these units were shipped hundreds of miles to their present site and it is entirely possible that they may be reshipped additional hundreds of miles to another site, if, as, and when, the need for them ceases to exist at Camp Stewart.

Shipping Via Truck-Trailer

In most of the 48 states, the maximum width of truck-trailer combinations, or loads placed thereon, cannot exceed 96″, if they are to move without restrictions or license. A height limitation also exists on the highways. This is set more by the height of the bridges and overpasses that are met en route than by any specific legislation. All the major trucking firms are, of course, familiar with these practical shipping requirements.

In the case of highway loads in excess of 96″, regulations vary from state to state. In some cases wider loads may move at off-peak hours with or without police escort, but with special permits. State authorities will often grant a permit for individual movements where they would not condone the handling of a number of similar units. A case in point was the Paducah, Kentucky Bomb Project where it took a Presidential Directive to finally get some of the units to the site.

Shipping Via Rail

The Association of American Railroads, which is an affiliation of all Class I railroads, has what is known as a main line clearance diagram. This is a vertical section drawing of a rather odd shape, the effect of which is that any car containing a load which does not project beyond the line of the drawing at any given point may move in unrestricted traffic over any line at any time. If the load does extend past this main line diagram, then the handling of the load will depend upon the route which must be taken and the maximum restrictions in any point on that route. Loads moving in this category are said to be moving under high and wide clearance and since these routings are generally devious, slow and a nuisance to the railroads, it is always desirable to avoid them wherever possible. Incidentally, the maximum main line diagram width is 10′ 8″.

In the case of the Camp Stewart housing, original plans were to ship the basic units on their side on flat cars and by so shipping, they would have been within the main line diagram. As events developed, however, it was possible to get high, wide clearance from Chicago to Camp Stewart over reasonable routes and, therefore, these houses have been and are being shipped upright.

The sections of the houses are not heavy enough to involve any problem in weight in highway shipping and it is interesting to note that the Camp Stewart house, shipped on its side on special low-bed trailers, will meet highway and height limitations. This was no small feat in design when it is considered that the 7′ 6″ inside clear height regulation has been maintained.

Floor loadings conformed to F.H.A. standards which require a minimum uniformly distributed live floor-load of 40 pounds per square foot. Roof loading, on fixed-to-site houses, of course, varies with the locale. It would be rather ridiculous to install a fixed-to-site house at Key West, Florida, designed to carry a two-foot snow load.

In the case of a relocatable house, the problem immediately becomes more involved in view of the unknown location of a possible future site.

However, in view of the number of prospective sites on which relocatable houses are desirable, it was felt by all parties concerned that if roof loadings were provided sufficient for the next northerly zone, as per H.F.A. standards, the requirements would be deemed to be met. The Camp Stewart houses are designed for 30 pound snowload which is satisfactory for most northern states, except the Great Lake and mountain states.

The present contract for relocatable housing at Camp Stewart calls for 65 three-bedroom units and the remaining 193 are two-bedroom units. The three-bedroom houses set on 13 piers or footings. The two-bedroom unit rests on 11.

Since the floor is an integral part of the monococque units, no concrete foundation slabs are required, as they are with prefab or fixed-to-site houses without basements. This obviously reduces both the time and material required for site preparation.

The subcontractor was able to prepare all of these footings in advance of the arrival of the units. In order to properly provide for mass assembly techniques, an ingenious type of footing adjustment is provided. By this means, even though the various footings may vary in height, the house can be readily leveled and the three sections adjusted to each other. Once this has been done, a small amount of wet concrete is placed on each of these adjustments so that they then

ecome set in nature. If the house is o be moved to another location, these djustment fittings are replaced.

All external walls, floors and ceilngs are fully insulated with fiberglass nsulation. This of course has the effect of holding the heat in in northern limes, as well as tending to keep the eat out in southern locations. The inlation is placed between the skins the time the cellular sections are ssembled and as might be expected henolic or resorcinol type resins are sed in the assembly. The gluing oprations are in most cases done in large lectronic presses.

Entire sides, floor and roof are nade as individual units and then ssembled into the shell, which go to form the units of the house.

In the design of the house, careful consideration was given to the use materials that are readily avail a result, all of the structural plywood, as well as the solid structural members, is of Douglas Fir. No beaverboard or similar material is used in the house. Other wood members may include western hemlock, spruce or pine, according to supply conditions. Interior walls, floors and ceilings are plywood. All floors are covered with vinyl-plastic floor covering.

The walls, floors, and ceilings and ends of the houses are literally welded to each other.

Both the two-bedroom and the three-bedroom houses at Camp Stewart are made up of three main sections, enclosing the same functional rooms. The so-called utility section is the same for both the two-bedroom and three-bedroom house. Roughly speaking, the houses may be said to be arranged in the shape of an "H" with unequal legs. The connection section of the "H" is the utility section. It is approximately 12′ x 10′ in size and contains the front entrance-way, connecting hallway, bathroom, utility room, and the so-called working section of the kitchen, including the range and sink, etc.

The second section in each case includes the bedrooms and a part of the hallway.

The third section contains the living room, dining room, storage, and the rest of the kitchen not encompassed by the utility section.

By means of this design, all plumbing is confined to the utility section. However, heating ducts appear in all three sections.

There is a fully adequate electrical system which conforms to underwriters codes including lights and outlets in all three sections and in every room and an electrical service entrance providing for range and four independent lighting circuits.

Figure 8.—Lowering a unit onto footings.

The interior surfaces of the Camp Stewart houses are being painted in a variety of colors. However, because of use of top grade plywood, natural finish could be used with equally good results. The overhanging eaves have a functional as well as appearance use.

The construction is such, and the elevations of the various roofs are planned so, that internal down spout can be used, connected directly with the sewage system.

The size and location of the windows, doors, etc. provide more than the minimum requirements for both ventilation and light and also give a full measure of safe exits in case of fire or other emergency.

Wood kitchen cabinets have been used throughout.

Erection at Site

The erection problems were briefly discussed earlier and it was stated that the three sections of the house are leveled on the preset footings and bolted together. The mating or meeting surfaces were jig-finished at the factory and include weather-tight gasketing and mechanical protection for the joints. In this manner the two "meets" between the three units are made weather-tight and protected against injury. Then the ornamental overhangs and patio trellis are installed by conventional methods.

Concrete slabs for the patio, steps at front and back door are provided locally.

The whole erection operation has been carefully time-studied and reviewed, so that the erection of the units goes forward in a smooth manner.

While the original intention was to apply finished exterior painting at the factory, this has been modified so that prime coating is factory-applied leaving the finish-coat to be applied at the site. There is a good reason for this change. There is a carefully worked out color scheme for the entire project to achieve a variety of exterior colors in adjoining houses. If the houses were all finish-coated in a variety of colors at the factory, then a logistics problem would be involved in being certain that the proper color houses were shipped in the proper sequence.

Houses Are Adaptable

In conclusion, it is only fair to point out that while these particular houses are being erected at an army base, they are in every way, shape and manner satisfactory for civilian use in the normal sense of the term. They are entirely appropriate for fixed-to-site housing, and conform to most if not all local construction ordinances.

The Camp Stewart House represents a new approach to the mass production of housing. The many eye-catching headlines which appeared in the papers and magazines throughout the country after the demonstration of the Camp Stewart prototype house in May 1952 were a measure of the public interest in this new approach to the age-old problem of housing.

The house is a resourceful and adaptable servant ready and able to do the every bidding of 20th century living, in war and in peace.

Perhaps the whole long-range implication of relocatable housing in general and the Camp Stewart house in particular were summed up in a remark made by a high government housing official at the end of the prototype demonstration, when he said: "Today I have seen the start of a new era in home building."

Discussion

W. W. King (Texas Forest Service): What is the approximate cost of these units?

Mr. Stanley: Approximately $8,000 F.O.B. Plant, including stove and refrigerator.

Properties of Beech in Tension Perpendicular to the Grain and Their Relation to Drying[1]

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In the drying of wood the surface layers tend to shrink around a relatively nonshrinking core. This results in tensile and compressive stresses perpendicular to the grain. Checks and splits result when maximum tensile strength is exceeded. Tensile stresses below maximum but beyond proportional limit cause "set." This paper describes fundamental stress-strain data for American beech in tension perpendicular to the grain at temperatures from 80° F. to 160° F. and moisture content from green to 6 per cent. Data on maximum stress, fiber stress at proportional limit, modulus of elasticity, and maximum strain are discussed in relation to wood drying.

Introduction

THE DETERMINATION of critical conditions for the development of drying checks in lumber and the establishment of a fundamental foundation for the determination of kiln schedules depends directly upon a knowledge of the strength and elastic properties of wood in a direction perpendicular to the grain.

It is generally recognized that, in the early stages of drying of a plank, shrinkage of the surface layers around a relatively non-shrinking core sets up tensile stresses in the surface layers and compressive stresses in the inner zones. Also, if wood is stressed beyond its proportional limit, "set" will develop, while checks and splits will result when the tensile strength of wood is exceeded in a direction perpendicular to the grain. The strength and elastic properties concerned will be modified in turn by moisture content, temperature, and the time for which the stresses are acting. A study of the strength and elastic properties in relation to the drying problem is therefore inseparable from a study of their modification by temperature, moisture content, and duration of stress.

Although the importance of quantitative data with respect to strength and elastic properties of wood perpendicular to the grain was pointed out as early as 1931 (3), the work carried out in this field has been extremely limited. Absence of data on strength and elastic phenomena has meant that trial and error methods have had to be used to a considerable extent in the development of kiln drying schedules. As a result, very conservative schedules have been developed.

In recent years the United States Forest Products Laboratory (8) has developed the stress analysis technique for charting the stresses occurring within a plank over the drying period. This technique consists of measuring the width across the grain of successive strips in depth of a drying plank. The strips are measured *in situ* in the plank and then again immediately after cutting from the plank, care being taken to prevent moisture loss. The change in dimension of the strip on cutting from the plank is interpreted to represent the degree of stress existing within the strip at the time of cutting, and the direction of the dimension change (expansion or contraction) to indicate the nature of the stress, that is, whether compression or tension. Application of this technique to the derivation of kiln schedules for hardwoods has reduced considerably the necessary drying times without increasing drying degrade. This is shown in the 1951 Kiln Drying Schedules, published by the Forest Products Laboratory (10).

However, to allow a proper and full interpretation of the strip technique of stress analysis, quantitative data on strength and elastic properties perpendicular to the grain are of paramount importance.

The apparent success of high temperature drying (at or near the boiling point of water) of hardwoods in Europe also emphasizes the need for closer investigation of mechanized and elastic properties. No satisfactory explanation is yet possible for the fact observed by Kollmann (6) that the amount of surface checking tends to be greater at lower temperatures of drying. Further, studies of the nature described above should afford basic information as to why the shrinkage of wood varies with drying conditions.

Previous Work

The comparatively limited work that has been carried out on the combined effect of temperature and moisture content on wood has, in the main, been restricted to properties concerned with structural design.

In 1936 Greenhill (4) published the first work on the effect of temperature and moisture content on the strength of wood perpendicular to the grain. Greenhill's investigation dealt with American beech, and was restricted to an examination of the tensile strength and elastic properties. The experimental difficulties encountered in this work were substantial, with the result that considerable judgment was exercised in the interpretation of a portion of the results, particularly at higher temperatures.

The curve for maximum load plotted against temperature was sigmoid

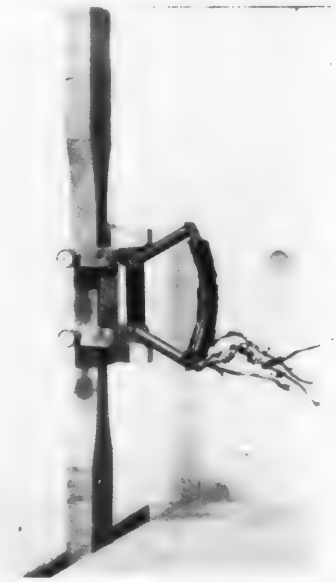

Figure 1.—Extensometer and clip gauge attached to tension specimen.

[1] This was the winning paper in the Graduate Division of the 1953 Wood and Wood Products Award Contest. Mr. Ellwood has since returned to his home in Melbourne, Australia.

for material tested in the green condition, with the maximum rate of strength decrease occurring between 100 and 155° F. The behavior of fiber stress at proportional limit and modulus of elasticity was similar in nature to that of maximum load. Perhaps the most significant result advanced by Greenhill was that maximum deformation at failure occurred at 124°F.

It was subsequently proposed that the optimum drying temperature for beech was 124°F, as the tensile stress in the drying plank could be accommodated by stretching rather than relieved by checking. The validity of such an hypothesis is critical in the further development of the drying theory. In actual fact, it has never been demonstrated that the optimum drying temperature of beech is 124°F from the standpoint of surface checking.

Kollmann (6), in 1950, published results of an investigation made in Sweden to determine the causes of injury in the drying of green oak. Tensile tests were carried out to determine maximum load of green material in the temperature range from — 70 to +100°C. The maximum load bore a linear relation to temperature from — 70 to 0°C, and from 0 to 100°C, with a discontinuity at 0°C for which no explanation was offered.

Kollmann concluded from his results that there was no indication of greater deformation at any particular temperature. In his experiment, however, the strain was measured by movement of the crosshead in the testing machine, with small magnification, and no attempt was made to estimate or correct for movement in the tension grips. Therefore, this evidence put forward by Kollmann cannot be accepted as conclusive.

Evidence (unpublished) advanced by Barnard-Brown and Kingston (1) on the green tension testing in Australia of two eucalypt species and myrtle beech shows a linear relationship between temperature and strength, and a trend towards an increase in deformation at failure with increased temperature. The results, however, are not considered conclusive by the authors, owing to the limited amount of material tested.

From the above review, the unsatisfactory state of knowledge on the strength and strain behavior of wood in a direction perpendicular to the grain is evident.

Experimental

Consideration of the stresses in a drying plank shows that the tensile and compressive strengths and elasticity perpendicular to the grain are the most important mechanical properties with respect to the development of degrade. Shear properties in the transverse direction will modify the mutual interaction of the tensile and compressive stresses in the drying plank.

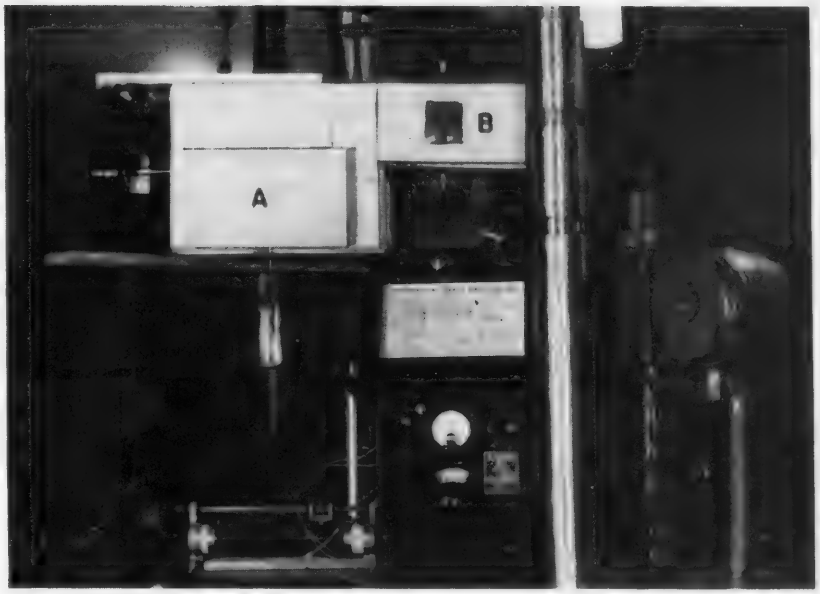

Figure 2.—Test arrangement for determination of strength properties under controlled conditions of temperature and humidity.

A. Heat and humidifying compartment.
B. Testing compartment between Templin grips.

In this paper, investigations are limited to a study of the influence of temperature and moisture content upon the strength and elastic properties of American beech *(Fagus grandifolia)* in a tangential direction, perpendicular to the grain. Exploratory tests were also carried out on repeated- and dead-loading effects. Provision has been made to test matched material in compressive properties under the same testing conditions as were used for the tensile tests. The latter investigation will be reported in a future paper.

Material: American beech was selected for testing as this species is prone to surface checking and, as far as is known, is not subject to liquid tension collapse which would introduce a further complicating variable into the study.

Green logs from six trees (105 to 260 years old) were sawed around the log to produce 1¼-in. planks at least 7 in. in width, with the least possible curvature of the growth rings. Material for test was taken only from the heartwood. From each log, the plank which contained the least amount of defect and the least curvature of the growth rings was marked into four sections. One of the four sections, selected at random, was then cut out from each plank, and stored in the green condition under damp sawdust treated with sodium pentachlorophenate to minimize strain and decay. The remainder of the material from each plank was kiln dried under mild conditions of 110°F dry-bulb and 107°F wet-bulb temperature, being changed to 120°F dry-bulb with 95°F wet-bulb temperature as drying proceeded. When the drying material successively reached approximately 18 and 12 per cent moisture content, one section from each plank was taken at random and stored in sealed bags. The remaining section of each plank was dried down to approximately 6 per cent moisture content before removal to a sealed bag.

The material for test was dried in plank dimensions as it was found that warping developed when the specimens were dried in test size. In addition, as drying checks (if present) develop in the surface zones of beech rather than in the interior zones, there would be little likelihood of drying checks being present in the finally shaped specimen as the surface zones were removed in the shaping operation.

All sections were then planed to dimension and the specimens cut out and shaped for test. Test specimens from each of the 6, 12, and 18 per cent moisture content samples and the green material were allocated at random to each of the five temperatures of test. After preparation, the specimens were kept for several weeks at room temperature in sealed jars over saturated solutions which afforded the appropriate equilibrium moisture content conditions.

Form of Test Specimen: The cross section of the actual test zone was 1/3 by 1/2 in., with a 2¾-in. radius

of curvature to the extended ends of the specimen which are held in the self-aligning friction (Templin) grips of the testing machine. The total length of the specimen was 7 in. Its shape is shown in Figure 1. This type of specimen was adopted in place of the American Society for Testing Materials specimen in order to permit making measurements of strain. Further, Keylworth (5) has observed that the necked-down specimen of the type used in the present experiment shows tensile strength values more closely approaching the true value than does the standard specimen.

Test Conditions: Specimens from each of the six logs were tested in duplicate at five levels of temperature in combination with four levels of moisture content, as follows:

Temperature: 80, 100, 120, 140, 160°F.

Moisture content: 6, 12, 18 per cent, green.

Thus, 12 specimens were tested at each of the 20 combinations of temperature and moisture content.

The experiment was designed as a randomized block 2 x 4 x 5 x 6 factorial. In the statistical analysis, account was not taken of variation of actual moisture content from the nominal moisture indicated.

Test Equipment: *Testing Chamber.*—A primary consideration was that the testing machine could not be withdrawn from use on other work during the course of this experiment. Therefore, a portable temperature and humidity chamber was constructed to control the temperature and moisture content of the specimens during test. The chamber was mounted on the crosshead of a Baldwin Southwark universal testing machine in such a manner as to enclose the specimen but not the Templin grips which held it (see Figure 2). With this arrangement, it was not necessary to heat the Templin grips to test temperature, and condensation trouble at high humidities was also minimized.

The chamber, as shown in Figure 2, consisted essentially of two sections, namely, the heating and humidifying compartment and the test compartment. The heating compartment contained a strip heater above which rested a tray of the appropriate saturated salt solution used to produce the required equilibrium moisture content. A fan mounted on the wall provided circulation through to the test compartment. The test compartment was designed to provide for free movement of the specimen and yet to maintain good thermal and vapor insulation. To achieve this, two layers of flexible rubber sheeting, with insulating material packed between them, were fitted closely around the extended ends of the test specimen. A window was built into the access door of the test compartment for observation of the specimen during test. Heat and vapor insulation of both sections of the chamber was obtained by packing the walls with glass wool and lining the interior with aluminum foil caulked at all joints.

Temperature control was obtained by means of a bimetallic on-off thermoregulator which was placed in the test compartment in the vicinity of the test specimen. In order to obtain optimum control of the temperature, it was found to be necessary to place a variable resistance in series with the strip heater to vary the heat dissipation of the heater according to the temperature desired. Under these conditions, the degree of control obtained, determined by shielded thermocouples, was ± 1.5°F.

To obtain humidity control, a survey was made of salts which would provide the desired equilibrium moisture content in saturated solution at the temperature of test. Final selection of the salts was made on the basis of equilibrium moisture content determinations of samples placed in the test chamber. Greatest difficulty with humidity control occurred at the higher operating temperatures, in attempting to attain 18 per cent equilibrium moisture content conditions. Trial runs with the salts finally selected indicated that the moisture content of the samples varied no more than 1.5 per cent moisture content from the set point.

Strain Measuring Device.—It was obvious that considerable difficulty would be encountered in obtaining accurate strain readings from the conventional strain gauges available. Electric variable resistance wire strain gauges were first bonded directly to the specimens, but the results were unsatisfactory as inadequate bonding was obtained on the green material.

The principle eventually adopted was that of the bending beam or clip gauge, with which repeated use of the SR-4 electric strain gauges is possible. In this device, a bent phosphor bronze beam, with resistance wire gauges attached to the concave and convex faces, is sprung into place between the "ears" of the extensometer. When the specimen is subjected to tensile strain the "ears" of the extensometer move apart and the curvature of the beam decreases. As a result, the gauge on the convex face is subjected to compression, and that on the concave face is subjected to tension. With the gauge on the convex face of the beam attached to the compensating gauge terminals of the SR-4 type K strain indicator, and the gauge on the concave face attached to the active gauge terminals, strain readings may be made on the indicator dial of the instrument. As the readings obtained are not a direct measure of the actual elongation between the points of attachment of the extensometer, the clip gauge must be calibrated to permit transformation of dial readings to unit strain measurements for the test specimen. Effects of temperature of test on the strain gauges are automatically compensated for, as both gauges are under the same environmental conditions.

The extensometer and clip gauge were constructed to perform over a 1-in. gauge length of the test specimen. Baldwin SR-4 type A-11 gauges were used for the low-temperature work, and SR-4 type AB3 gauges for the higher temperatures and humidities. A 2-in. length of phosphor bronze of 0.018-in. thickness was bent to a 4-in. radius of curvature. Arms extending towards the axis of curvature were placed on the ends of the strip to provide contact with the extensometer. Gauges were cemented to the convex and concave faces of the beam with Armstrong's A_1 epoxide resin.

The extensometer to hold the clip gauge was made from aluminum alloy to minimize weight. The extensometer and clip gauge assembly are shown attached to the specimen in Figure 1.

The clip gauge was calibrated under room conditions against A-11 gauges cemented directly to the surfaces of several specimens. Readings within the proportional limit were taken successively with the clip gauge and the direct reading gauge, and a conversion factor obtained.

Testing Procedure: In order to distribute error in experimentation, the experimental material was divided into groups of six specimens, each group of six containing one specimen from each log, so that one replicate of the material was tested at a time. The order of testing at the 20 combinations of temperature and moisture content, each to be set up twice, was also randomized.

The sequence of events in testing was as follows. A group of specimens was taken from the sealed salt solution container where they had been maintained at a pre-determined moisture content at room temperature, and placed in a small conditioning cabinet in which the temperature and humidity conditions were the same as those required for testing. The oven-dry weight of each sample had been previously estimated from moisture content samples cut during the forming operation. Consequently, a close check

on the specimen moisture content was available at all times by weighing. After 2 hours in the conditioning cabinet, the specimen was transferred rapidly to the test chamber, which had been brought previously to the operating conditions. The specimen was fitted with the extensometer and clip gauge and then clamped in the friction grips. After the specimen was inserted, 5 minutes were allowed for stabilization of the chamber before testing.

The rate of loading was controlled to 0.015 in. per min. over the 4½ in. between the Templin grips, and the load increments taken were appropriate to the estimated maximum load of the specimen. Strain was recorded manually until failure of the specimen with an SR-4 type K strain indicator.

After failure, the net section of the specimen was measured with a machinist's micrometer. The net section was broken out, weighed, and oven dried to determine the actual moisture content at test. All sections which did not fail in the net section were discarded. A Breuil mercury volumeter was used to obtain volumes for the calculation of specific gravity based on oven-dry weight and oven-dry volume.

Stress-strain curves were plotted for specimens, and maximum stress, modulus of elasticity, fiber strees at proportional limit, and maximum unit strain were computed.

Results

In general, good control of moisture content was obtained by using the technique of periodically checking the weight of the specimens during the conditioning period. The maximum deviation of any group of specimens from the control moisture content was 0.8 per cent. The greatest difficulty encountered was in stabilizing the moisture content of the 18 per cent moisture content specimens at the higher temperatures.

On the whole, the clip gauge behaved satisfactorily, although some trouble was experienced because of breakage of the fine lead wires during handling. Special attention in waterproofing the lead wires was also necessary to prevent electrical short circuits at the higher humidities.

Although the temperature tended to fall slightly below the control point when the specimen was introduced into the testing chamber, temperature variations were restricted to ±2°F. about the control point during actual test.

Experimental data obtained for the effects of temperature and moisture content on the tensile strength and elastic properties are given in Table 1. Fitted curves for the effect of temperature on strength and elastic properties

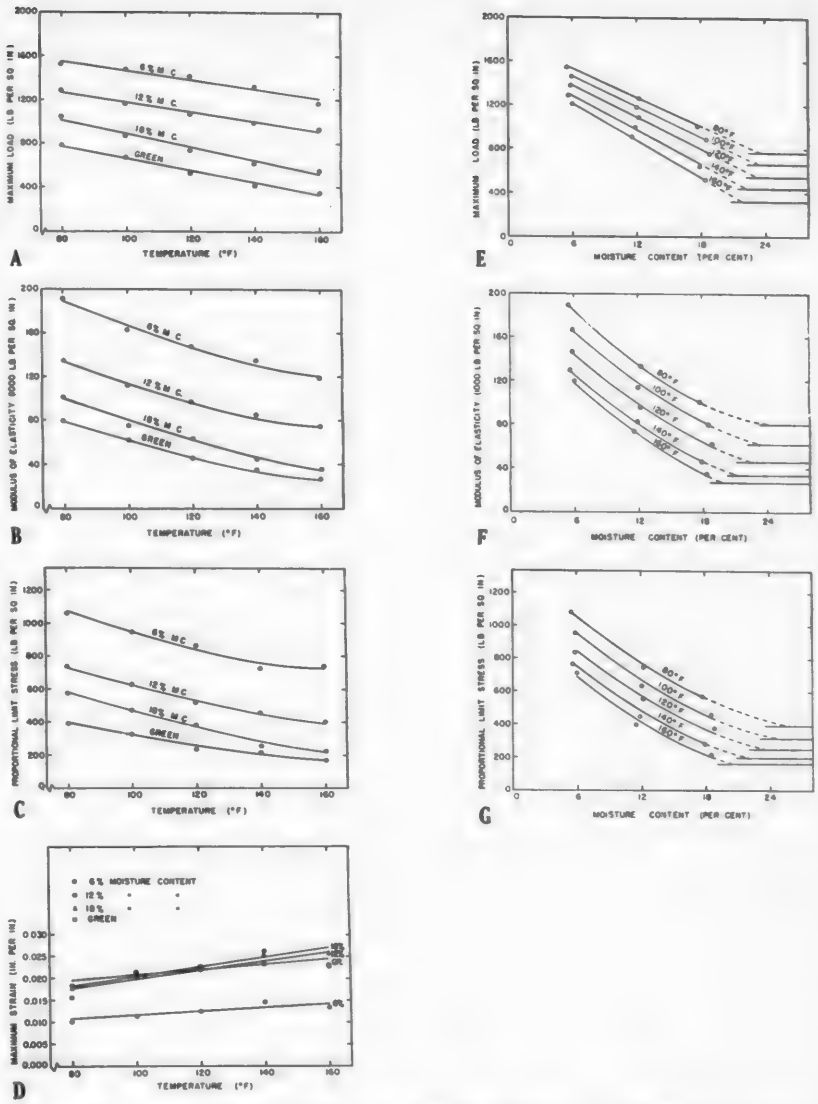

Figure 3.—Effect of temperature and moisture content on mechanical properties of beech in tension perpendicular to the grain.

A, B, C. Mathematically fitted curves at nominal moisture contents.

D. Freehand curves at nominal moisture contents.

E, F, G. Freehand curves at actual moisture contents. Points taken from fitted curves in Figure 3 A, B, and C.

Table 1—EFFECT OF TEMPERATURE AND MOISTURE CONTENT ON PROPERTIES OF AMERICAN BEECH IN TENSION PERPENDICULAR TO THE GRAIN (TANGENTIAL DIRECTION)

Nominal Temp. (°F)	Nominal Moisture Content (per cent)	Actual Moisture Content (per cent)	Maximum Load (lb. per sq. in.)	Modulus of Elasticity (100 lb. per sq. in.)	Fiber Stress at Proportional Limit (lb. per sq. in.)	Strain at Maximum Load (in. per in.)
80	6	5.5	1523	1916	1078	0.0100
	12	12.2	1289	1347	741	0.0155
	18	17.7	1040	1011	569	0.0179
	green	89.4	782	799	395	0.0183
100	6	5.9	1475	1628	952	0.0113
	12	12.0	1166	1109	637	0.0214
	18	18.5	863	752	472	0.0209
	green	89.3	666	620	330	0.0213
120	6	5.8	1411	1481	873	0.0125
	12	12.2	1061	970	525	0.0220
	18	18.8	737	634	375	0.0224
	green	85.6	522	454	246	0.0225
140	6	5.6	1321	1350	726	0.0147
	12	11.9	987	825	465	0.0268
	18	17.9	618	450	262	0.0257
	green	81.4	418	356	225	0.0231
160	6	6.0	1177	1190	746	0.0134
	12	11.5	992	749	402	0.0227
	18	18.3	552	360	236	0.0261
	green	81.9	350	263	162	0.0229

for the nominal 6, 12, 18 per cent and green moisture contents are shown in Figure 3 A, B, and C. Table 2 shows the regression equations of temperature upon strength and elasticity at the four moisture contents tested. Figure 3 E, F, and G shows the effect of moisture content upon the strength and elastic properties for the nominal temperatures of 80, 100, 120, 140, and 160°F. The latter curves were obtained by drawing freehand lines through the strength values obtained from the fitted curves in Figure 3 A, B, and C, plotted against actual moisture content at test. These curves were extrapolated to the strength in the green condition.

Figure 3 D shows the effect of temperature on strain at failure for the nominal moisture contents of 6, 12, and 18 per cent, and for the green condition. The relationship is represented by freehand curves.

The mean specific gravity of the material tested was 0.72.

Table 2—EFFECT OF TEMPERATURE AND MOISTURE CONTENT ON THE TENSILE STRENGTH AND ELASTIC PROPERTIES OF AMERICAN BEECH PERPENDICULAR TO THE GRAIN (TANGENTIAL DIRECTION) IN THE TEMPERATURE RANGE 80 TO 160° F.

Property	Moisture Content (per cent)	Regression Equation of Property on Temperature	Significance of Temperature Effect
Maximum load	6	$y = 1888.20 - 4.225x$	
	12	$y = 1622.28 - 4.460x$	L*
	18	$y = 1494.48 - 6.101x$	
	green	$y = 1215.45 - 5.564x$	
Modulus of Elasticity	6	$y = 3210.64 - 20.290x + 0.0485x^2$	
	12	$y = 2659.02 - 21.002x + 0.0567x^2$	L* Q*
	18	$y = 2263.15 - 19.657x + 0.0485x^2$	
	green	$y = 1881.74 - 16.950x + 0.0428x^2$	
Proportional Limit Stress	6	$y = 1949.97 - 14.002x + 0.0398x^2$	
	12	$y = 1394.76 - 10.082x + 0.0243x^2$	L* Q*
	18	$y = 1215.70 - 9.802x + 0.0225x^2$	
	green	$y = 783.04 - 5.820x + 0.0122x^2$	

L = Linear component.
Q = Quadratic component.
* = Significant at 1 per cent level.
x = Temperature (°F).
y = Computed property value in lb. per sq. in. for maximum load and proportional limit stress, and 100 lb. per sq. in. for modulus of elasticity.

Discussion of Results

Maximum load showed a highly significant[1] linear trend with temperature for all moisture contents, in contrast to a sigmoid relationship found in earlier tests on this species. The present results conform with the trend found by Kollmann for green oak, and by Barnard-Brown and Kingston for three Australian species.

A highly significant difference of temperature effect with moisture content was found. The temperature coefficient was greatest at 18 per cent moisture content (see Table 2 and Figure 3 A).

Table 3 shows a comparison of the limited data available on the effect of temperature upon tensile strength perpendicular to the grain. It can be seen that there is a considerable variation in temperature effect between species. A greater strength decrease with temperature than has been published previously was found for beech, although the difference between results is somewhat reduced if the strength decrease is expressed as lb. per sq. in. per degree F.

Up to 18 per cent moisture content, the effect of moisture content on strength showed a highly significant linear relationship (see Figure 3 E). The moisture content effect increased with increasing temperature. The curve for each temperature group was extrapolated to the green strength at that temperature.

It should be noted that the moisture content—tension perpendicular to the grain strength relationship departs from the usual exponential law assumed to hold generally for wood properties at room temperature (11). In this connection, Sulzberger (9) found that the crushing strength parallel to the grain also departed from the exponential law, and that the actual relationship depended upon the temperature of test.

It is interesting to note that both the 12 per cent and green specimens used in this investigation, when corrected for specific gravity,[1] showed higher values than those given by the ASTM method of testing (7). A closer approach to the true tensile strength by use of the test specimen employed in this study is therefore obtained probably as a result of reduced stress concentrations in the specimen.

The effect of temperature upon modulus of elasticity showed highly significant linear and quadratic components (see Table 2 and Figure 3 B), although the quadratic component was very small in comparison with the linear component. This trend differs from the sigmoid relationship between modulus of elasticity and temperature previously published for this species, and tends to be more similar to the linear relation found from limited tests in the green condition for three Australian species. It can be seen from Table 3 that the percentage reduction with temperature in modulus of elasticity of green beech is considerably greater than values previously published. The linear temperature coefficients for the 6, 12, and 18 per cent moisture content series were significantly greater than the linear temperature coefficient for the green series.

In the moisture content range of 6 to 18 per cent, modulus of elasticity showed a highly significant linear and quadratic decrease with increasing moisture content. The relationship was extrapolated to green values as shown in Figure 3 F. The decrease in strength with increasing moisture content appears independent of the temperature within the temperature range tested.

Reduction of fiber stress at proportional limit with increasing temperature is largely accounted for by a linear component, but, as in the case of modulus of elasticity, a relatively small quadratic component was highly significant. Again, the linear temperature coefficients for the 6, 12, and 18 per cent moisture content series were not significantly different, and were greater than the temperature coefficient for the green material (see Figure 3 C).

Within the moisture content range of 6 to 18 per cent, the reduction of fiber stress at proportional limit with increasing moisture content is accounted for by highly significant linear and quadratic components. The effect of moisture content upon the fiber stress at proportional limit was not markedly influenced by the temperature of test (see Figure 3 G).

The extrapolation of the curves for maximum load, modulus of elasticity, and fiber stress at proportional limit, plotted against moisture content, shows that fiber saturation point (or the intersection point) decreases with increasing temperature of test. This behavior is in conformity with other observations (12) and justifies the extrapolation.

Considering strain relationships, the strain at proportional limit showed large variations between logs, and showed no trend with temperature or moisture content of test. The strain at proportional limit varied from 0.004 to 0.007 in. per in., depending on the material.

Strain at failure for the test material is shown in Figure 3 D. No attempt was made to fit regression curves, as many interactions were highly significant. Specimens at all moisture contents showed a highly sig-

[1] The term "highly significant" denotes a difference or trend which is statistically significant at the 1 per cent level. The term "significant" applies at the 5 per cent level.

[1] Direct proportionality between specific gravity and tensile strength was assumed, in the absense of data on the precise relationship between these two properties.

nificant linear increase in maximum strain with increasing temperature of test, but significant curvilinear effects were present. There was no trend to greatest deformation at failure in the vicinity of 124° F, as found by Greenhill, although some moisture content groups showed a slight decrease in strain at 160° F.

Maximum strain at 6 per cent moisture content was considerably less than that at all other moisture contents at all temperatures. At 80° F, the 6, 12, and 18 per cent and green moisture content series fell into a series of successively higher maximum strain values. At higher temperatures, the difference in maximum strain between the 12 and 18 per cent moisture content and green groups was not large, indicating a very similar maximum strain at these moisture contents.

In general, considerable differences are apparent between earlier work and the present investigation in the effects of temperature and moisture content on the tensile strength properties of beech. It is considered that these discrepancies are due largely to insufficient moisture content control of the specimen in the earlier investigation, as the facilities available for such control have since been much improved. Considerable judgement was therefore apparently exercised in locating curves, with the result that some trends were shown in the earlier work which are now known to be untenable, for example, the absence of a temperature effect on the strength of oven-dry wood.

It is not yet possible to determine whether other species of wood react similarly to beech with respect to the effect of temperature and moisture content, but differences are apparent in the very limited data available.

Relation to Drying Stresses

Full and proper application of the above results to the drying procedure can only be made by their integration with other properties relative to stress and strain in the direction perpendicular to the grain. The most important of these properties are compression perpendicular, shear, and the modifying effects of prolonged loading upon the properties. However, at this stage several points can be brought out from the data presented.

Consideration of Figure 3 E and G shows that the $\frac{r^1}{m}$ ratio decreases with increasing temperature and also with increasing moisture content. Consequently, the plastic range is extended with increased temperature and increased moisture content. Thus, tension set will occur at lower loads under conditions of higher moisture contents and/or higher temperatures.

r = fiber strees at proportional limit
m = maximum stress
E = modulus of elasticity

Table 3—TEMPERATURE EFFECT ON STRENGTH AND ELASTIC PROPERTIES IN TENSION PERPENDICULAR TO THE GRAIN FOR GREEN SPECIES IN THE TEMPERATURE RANGE 80 TO 160° F.

Source	Species	Average decrease in strength per degree F increase in temperature as percentage of green values at 80°F.		
		Maximum Stress	Modulus of Elasticity	Proportional Limit Stress
Present work	American beech	0.71	0.84*	0.72*
Reference (4)	American beech	0.56*	0.66*	0.62*
Reference (6)	European oak	0.57	-----	-----
Reference (1)	Myrtle beech	0.73†	0.99†	0.65*†
Reference (1)	Alpine ash	0.63†	0.95†	0.58†
Reference (1)	Mountain ash	0.59†	0.59†	0.55*†

*Non linear components included.
†Approximate values.

Similarly, consideration of Figure 3 E and F shows that the $\frac{E^1}{m}$ ratio is at a maximum at low temperature and low moisture content, and decreases with increasing moisture content and with temperature. Stiffness is reduced relative to maximum stress with increasing temperature and moisture content, and therefore greater deformation per unit stress may occur under these conditions.

As has been previously pointed out (1), the fiber stress at proportional limit is practically always exceeded in the drying of lumber. Therefore, to evaluate the stresses currently present in a drying plank by the technique of strip analysis, the "set" component of strain must be added to the elastic recovery of the strips to determine the actual stress in the strip.

A quantitative knowledge of the stress-strain curve for different conditions of temperature and moisture content, as afforded by the data presented, should allow a more accurate determination of stresses existing in a given strip.

Comparatively small increases in maximum strain in tension are produced by increasing temperature. Because strain at proportional limit was practically constant for all combinations of temperature and humidity tested, increases in maximum strain were of a plastic nature. It is therefore contended that any increase in the ability of beech to resist surface checking by greater deformation at higher temperatures would be very slight, as comparatively small stresses could account for a small plastic strain. Of greater import is the much reduced maximum strain at low moisture contents.

Because duration of loading considerably affects strength properties in general, several exploratory tests were carried out to determine trends in tensile strength properties as influenced by duration of stress. A limited number of specimens were held in tension for 2 hours at a constant load above the proportional limit. The constant load value was approximately 85 per cent of the maximum load of closely matched controls which were loaded to failure at a constant rate of 0.015 in. per min. Considerable creep was evident. Strain was observed to increase with successively diminishing increments with time to a point where further increases in strain were hardly discernable. The initial rate of strain increase was greatest in the specimens which were loaded at high moisture content and temperature. In all cases, the maximum load which the specimens could resist after 2 hours was less than that of the controls, which were loaded to failure at the constant rate of loading prescribed earlier. Several specimens also failed without further increase of load. There is therefore reason to believe that creep occurs relatively rapidly in tension perpendicular to the grain, and that the time required to produce maximum set is relatively short in terms of the total drying time of a plank.

A point of considerable interest was whether total strain in tension was affected by the duration of loading. In the limited number of tests carried out, the maximum strain of the specimens tested under a 2-hour duration of load was similar to that of the controls which were loaded at a constant rate to failure. It was also found that the apparent modulus of elasticity was increased when loading at a constant rate was continued after the specimen had been maintained at a constant load above the proportional limit.

Figure 4 A shows the increase in modulus of elasticity obtained in a specimen which was loaded and unloaded, until it failed, to 88 per cent of the maximum static load of a closely matched control. The test was carried out at room conditions with the specimen at 6 per cent moisture content. The implication from this is that the elastic recovery curve will be steeper than that anticipated from the original modulus of elasticity. Thus, in the strip technique of stress analysis, the stress present in a strip

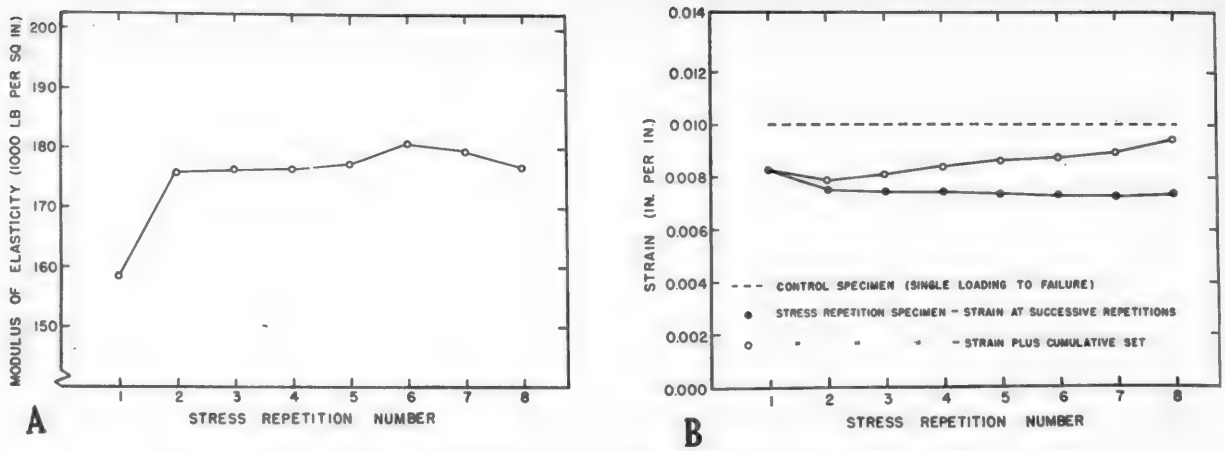

Figure 4 A and B.—Effect of repetition of load in tension perpendicular to the grain on the modulus of elasticity and strain behavior of beech at 6 per cent moisture content and 80° F.

would be closer to the maximum stress of the material than would be predicted from the stress-strain curve obtained for short term loadings.

Figure 4 B shows the strain at each successive repetition of loading plus the cumulative set resulting from previous loadings. It is seen that the total strain at failure closely approaches that of the statically tested control. It is therefore suggested that, although maximum strength is reduced by increasing the duration of loading, maximum strain is not particularly affected. The total strain at any stage may therefore afford an indication of the proximity of the specimen to failure, irrespective of the duration of stress.

Summary

1. An experimental procedure was described for determining the effect of temperature and moisture content upon the strength variation of American beech in tension perpendicular to the grain in a tangential direction.

2. Within the temperature range of 80 to 160° F, and moisture content range of 6 per cent to the green condition, the following was established:

i. Maximum stress, modulus of elasticity, and fiber stress at proportional limit decrease with increased temperature and moisture content. On a percentage basis, modulus of elasticity was most affected by changes in temperature and moisture content.

ii. Maximum showed a linear relationship with both temperature and moisture content. The maximum temperature effect was found at 18 percent moisture content, and the moisture content effect increased at higher temperatures. Regression equations of maximum stress on temperature for various moisture contents were given.

iii. The relationship of both modulus of elasticity and fiber stress at proportional limit to temperature was predominantly linear, but significant curvilinear effects were present. With both properties, the effect of temperature appeared least for the green material. Both properties bore a curvilinear relation to moisture content. No marked temperature effect on moisture content relation was apparent. Regression equations were given for both properties on temperature at the nominal moisture contents of test.

iv. Maximum strain at 6 per cent moisture content was markedly lower than that obtained at the other moisture contents involved in these tests. Maximum strain increased in a predominantly linear manner with temperature at all moisture contents, although increases were comparatively small.

3. An interpretation of drying behavior was given in relation to the data presented.

4. Limited tests on the effect of duration of load were carried out. Although results were not final, owing to the limited testing, trends were described, and the modifying influence of these trends in relation to drying stresses were discussed.

Acknowledgements

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The author wishes to express his appreciation to Professor F. F. Wangaard, immediate supervisor of the investigation, for his constructive criticism of the work and manuscript.

Thanks are also due to Mr. J. M. McMillen of the U. S. Forest Products Laboratory, Madison, with whom the general problem of drying stresses in lumber was discussed. Considerable advice on the construction of the clip gauge was obtained from Mr. K. Boller of the same Laboratory.

The logs for this study were made available by several private and government organizations at the request of Dean George A. Garratt of the Yale Forestry School.

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Discussion

Roy M. Carter (North Carolina State College): This paper indicates that high temperature does not cause checking. What is the effect of high temperature on strength?

Mr. Ellwood: There is a decrease in strength due to temperature, but there is an inter action effect.

H. J. M. Jorgenson (Jorgenson-Bennett Manufacturing Company): The fact that wood (Beech) loses strength as temperature increases does not mean that the loss of strength is permanent or that the wood dried in such a manner would be inferior.

Mr. Ellwood: The strength loss which is incurred is not permanent.

John M. McMillen (U. S. Forest Products Laboratory): Mr. Ellwood is to be complimented for the fine work done on this paper. The Forest Products Laboratory is presently doing work of a similar nature on another species, and more work in this field is needed. Do the results of this paper indicate that a new kiln schedule can be applied to Beech?

Mr. Ellwood: Before a new schedule can be determined, the creep and relaxation effects must be measured. We must know what happens to the deformations in the wood.

John Devine (Moore Dry Kiln Company): Practical experience indicates that Beech might stand much higher temperature than the usual schedule. It dries with less checking in the kiln than in air.

STATISTICAL METHODS

(Continued from page 15)

and in particular, the portion of the paper possessing brightness outside the band he is accustomed to receiving.

Conclusion

This paper attempts to present the steps which should be taken in formulating a modern quality control program. These steps involve the establishment of (a) significant and reliable quantitative measures of product quality, (b) realistic specifications which take into account customer needs, manufacturing capabilities, and costs, (c) a raw materials inspection program, (d) a system of controlling quality during the manufacturing operations, (e) a technical group to aid in the correction and improvement of unsatisfactory operations, and finally (f) an agency independent of the Manufacturing Department to measure and report to top management the degree to which the finished product is meeting customer requirements. The Forest Products Industries will find that statistical concepts and methods supply valuable and often necessary aids in the development of a quality control program to meet present day needs.

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Discussion

E. O. Lieberg (Wood Conversion Co.): How does sampling fit into this program?

Dr. Noble: This discussion is not all inclusive and in the time allotted, it is not possible to cover the subject of sampling adequately. Sampling is often troublesome in our industry and in your industry. It is very important in statistical work to obtain unbiased samples. For example, we sample paper at the end of the roll and assume that we have an unbiased sample. The success of our application of statistical techniques may well depend upon the correctness of this assumption. One of the difficulties encountered in using statistics is that they are frequently used for support rather than for illumination. The literature is filled with examples in which carefully applied statistical methods gave erroneous results because of improper sampling. Statistical tools are sharp and if they are to be used successfully they must be understood. This certainly applies to the question of sampling.

QUALITY CONTROL

(Continued from page 24)

furniture manufacturing, that these techniques hold great promise and can bring to the furniture manufacturing industry many of the spectacular quality improvements and cost reductions they have brought to other industries.

Little use has been made to date of the statistical quality control tools known as "C" charts and "P" charts except as a guide to proper location of the more sensitive $\bar{\bar{X}}$ and R charts in machining operations. Undoubtedly they will be used more frequently as a means of checking the general quality level in various production cycles.

The problems arising in the contemplated application of statistical quality control techniques to furniture finishing offer a real challenge to an imaginative quality control engineer. Certainly the trend towards making furniture finishing a science rather than an art holds promise in reducing finishing quality characteristics to measurable quantities. At present, the use of C and P charts would seem to be the most logical approach. Considerable thought is developing toward techniques to take the emotion out of

visual inspection and to reduce it to a scientific endeavor. Perhaps, herein lies the answer.

The author would again caution, that in contemplating a quality control program of the nature described herein, a tremendous amount of planning should be done, before such a program is launched. Ways and means of selling the quality control ideal to all facets of the organization—from top management to the workers—must be found. A proper climate, in which the quality control idea can thrive must be created. Ways and means must be found for obtaining prompt and effective action from all operating personnel when quality falls off. Quality Control must, finally, be more than merely another staff department set up to hamper the production departments. It must become fully, a part of *their* thinking and *their* creed!

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Discussion

Ross Martin (Sears Roebuck): Do you think that we can apply statistical quality control to finishing operations unless we get standardization of finishing?

Mr. Calahan: Yes, we can. The use of "p" or "c" charts is valuable. I am looking forward to the time when quantitative measures will allow the use of $\frac{}{X}$ and B° charts for finishing. We are trying a de-merit point system. It is not fully developed as yet but is very promising.

Mr. Latimer: The liquor industry uses a very ingenuous method of pooling opinions of various people in a scientific way to control the taste of their product.

END PRODUCT

(Continued from page 27)

Mr. Ripley: If an unapproved glue is used, we do not permit the use of DFPA grade marks. Our method of policing all quality standards is based upon our right to withdraw use of grade marks.

Mark W. Deichman (Taylor-Colquitt Company): Would not a large operation find it more advantageous to concentrate on producing a quality product of its own without participating in an industry-wide quality control program?

Mr. Ripley: The large operators in the Douglas Fir Plywood Industry have consistently participated in the industry-wide quality control program. They apparently feel that there is a sales advantage associated with membership in the plywood association and the right to use association grade marks.

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WORKING IN THE PACIFIC NORTHWEST TO CREATE A PERMANENT FOREST INDUSTRY

Aubrey E. Wylie (New York State University): On the average what period of time elapses between the gluing operation and the time when the report on laboratory tests is received by the manufacturer?

Mr. Ripley: We do not pretend to control individual lots. Our quality control program is based upon process control. We try to control spread, glue mix, veneer quality, etc. If the quality of a particular manufacturer goes down and remains down, his authority to use association grade marks is withdrawn.

Stephen Preston (University of Michigan): Is any attempt made by the Douglas Fir Plywood Association to control the final thickness of the face veneers of panels after sampling?

Mr. Ripley: Yes. This is a part of the grading procedure. Rough sanding is considered to be a defect.

Mr. Preston: I am thinking of the final thickness of face veneers.

Mr. Ripley: No, there is no specification for the final thickness of the face veneer.

SOME APPLICATIONS

(Continued from page 31)

which are outside of the control limits either on the high or low side may indicate poor selection of samples or over correction in the operation of the kiln.

Edward P. McMahon (Nickey Bros.): Why was it decided to treat moisture content as a variable in the control of the final moisture content of kiln dried redwood.

Mr. Pratt: From a given number of samples you can get more information by treating moisture content as a variable than you can by treating it as an attribute. We have been unable to find a rapid method of accurately determining the moisture content of redwood. The oven method is usually used. This is time consuming, costly and wasteful, and accordingly it is desirable that we obtain the maximum information from the samples. With other species, where a moisture meter will work better than it will with redwood, an attribute method might be satisfactory.

Mr. McMahon (Nickey Bros., Inc.): Has your association made any study of the statistical aspects of the sampling problem involved in selecting the given sample boards used in operating the dry kiln.

Mr. Pratt: No. We have tried to segregate redwood into two categories, wood which is less than 100% moisture content is classified as light and wood which is more than 100% is classified as heavy. Samples are selected from the slowest drying boards, that is, those with the highest moisture content. These boards usually have a high number of rings per inch and a dark color with a bluish cast. Dry lumber is not hurt by a mild schedule. Wet lumber collapses and is subject to other drying defects when dried on a severe schedule.

William S. Delmhorst (Delmhorst Instrument Company): Where we have a material which has a variation in its physical characteristics that affects the final condition of the end product and a process that will also effect the final condition of the end product, can samples be taken from certain locations be used as randomized samples for quality control?

(Recorder's Note to Editor): I believe that what Mr. Delmhorst is asking is: Two variables in the kiln drying of lumber. The moisture content of the wood is variable and the kiln is not uniform in its drying characteristics from place to place. Is a random selection of samples under these circumstances appropriate?

Mr. Pratt: We try to eliminate what variables we can and then to minimize the effect of remaining variables through random sampling.

Dr. Noble: It is necessary to get information on the nature of effects. If variables are independent, there is no problem; if they are dependent, interactions will present analytical problems. If you draw samples at random,

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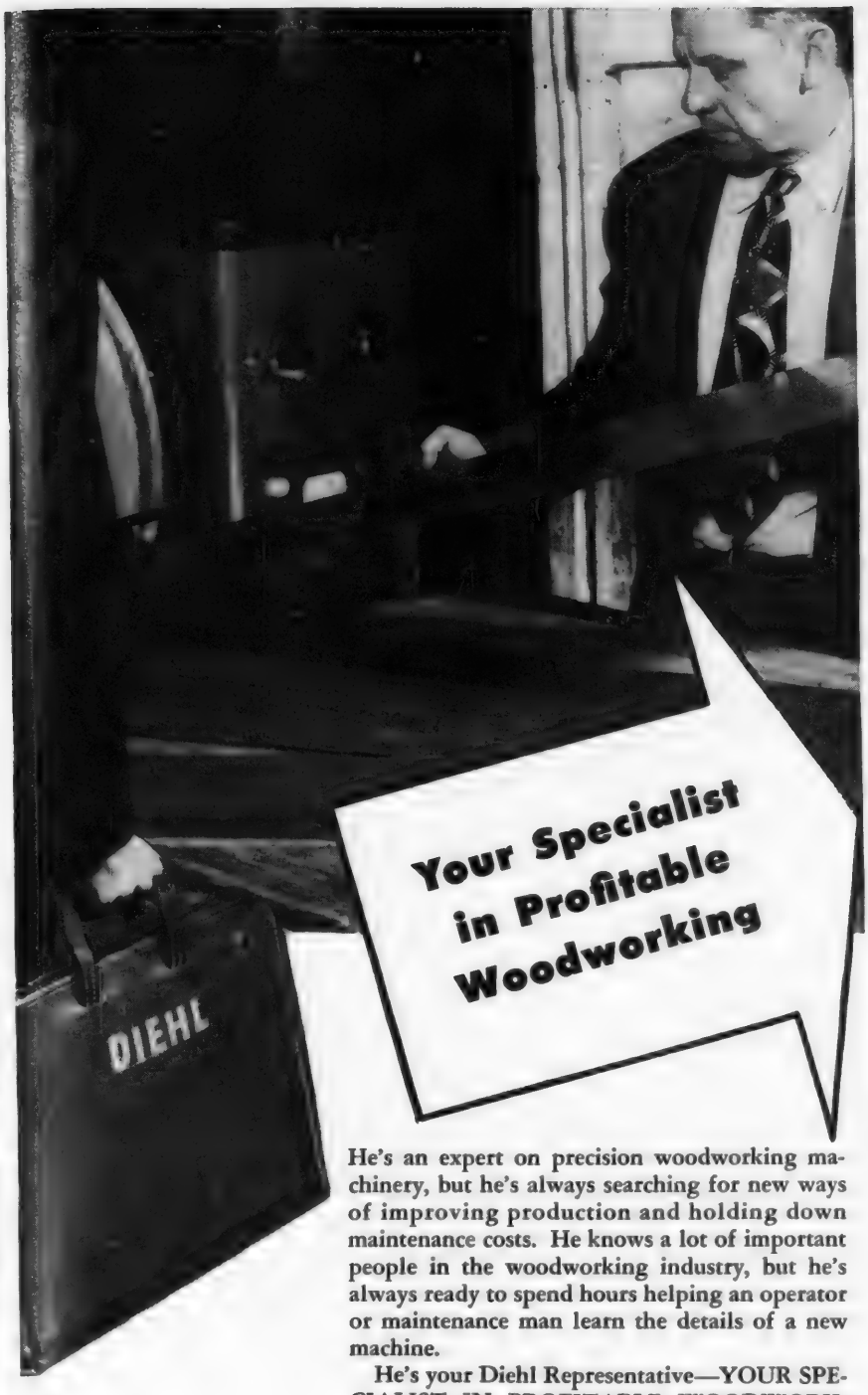

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Mr. Delmhorst: Can samples taken from the same location in successive operations of the same places be used to indicate faulty operations of the process?

Dr. Noble: If you want to get your variability within a charge, you should take a random sample until you know what pattern of variation is present. When you know the pattern of variation, you are now in a position to use stratified sampling techniques.

John McMillen (U. S. Forest Products Laboratory): There are two reasons for sampling in lumber drying: 1. To control the drying operation. 2. To see if the results are good. For the latter random sampling is appropriate. For the former the Forest Products Laboratory recommends selection of an adequate number of kiln samples from the slowest drying material plus a few from the fastest drying material. The kiln schedule is followed on the basis of the average moisture content of the wettest half of the slowest drying samples. Towards the end of the drying the kiln conditions are adjusted to stop drying of the driest material at a moisture content somewhat below the desired lower limit. The wettest material continues to dry to slightly below the upper limit. Surface and average moisture content can then be brought up, as well as casehardening relieved, by a conditioning treatment. Thus the drying process is capable of modification to bring the moisture content of all the material within desired control limits. It may be more practical in some cases to do this by lengthening the last drying step, rather than by prolonging the equalization, as was indicated by Mr. Pratt.

PRODUCTION GLUING

(Continued from page 34)

The higher labor cost of $25 per day for Parenthetical is saved many times over by the advantage of $218 in glue cost, $24 in cross-banding, $150 in low rejects. The total of approximately $400 a day saved by proper attention to the job may not appear large compared to the $15,000 ex-factory value of the panels but it comes to $100,000 a year which could be a large share of the company's profit. The value of the intangibles such as uniformity and reliability are hard to measure but considerable.

Discussion

G. A. Seidel (Splicedwood Corp.): We question value of using our own catalyst system because of chance of foreman getting wrong materials.

Mr. Casselman: Glue companies don't accept responsibility for their's either.

Mr. Seidel: How do you measure pot life?

Mr. Casselman: By water bath. One sample goes to foreman; one to laboratory. Sample taken every 40 minutes.

Mr. Seidel: If catalyst is more flexible, why short time?

Mr. Casselman: Found ready mix problem brings problem of non-uniform product.

Mr. Seidel: Can you depend on a foreman to control spread, amount of catalyst?

Mr. Casselman: Foreman should have assistant to check details.

Mr. Seidel: The man checking should be independent of the crew.

Henry Espel (Baldwin Co.): What is effect of catalyst on core penetration?

Mr. Casselman: We've never found any difficulty in adding extender.

B. C. Williams (Norfolk Naval Shipyard): I agree with Mr. Seidel about checks by weight and the use of foreman for checking. Pot life goes to

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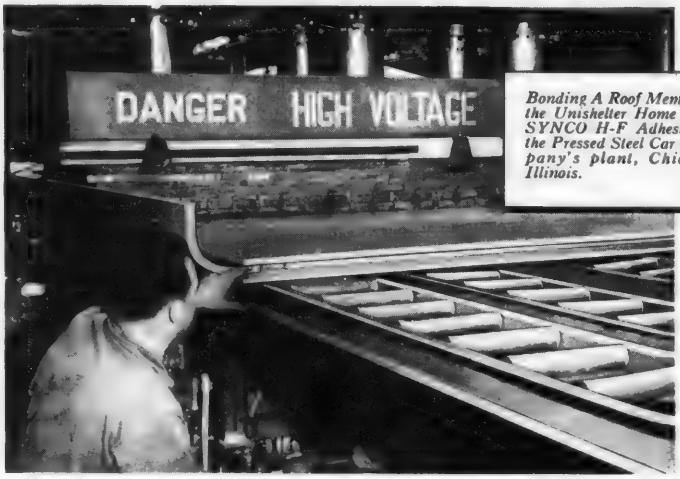

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"pot" while you're making your checks. In long timbers you get an uneven spread which makes you question the value of sample checks. On day after runs are checks necessary?

Mr. Casselman: Don't stop operations during check period. But you learn with check whether you need to keep bale under pressure longer. Also test bale after it comes from press. You can't depend on inertness with urea glues.

Mr. William: Have found test not worth it. Do you have trouble with viscosity of glue, especially with glue failing to fall on the rolls fast enough for a good spread?

Mr. Casselman: Use an aluminum cup with hole and check time for glue to run through as rough check.

Mr. Williams: I think it would be better to package excelerator and glue in double can.

Mr. Casselman: The problem is less with liquid resin than with solid.

E. A. Patton (Curtis Cos., Inc.): Do you require your glue room people to turn in records of glue spread in order to insure their proper attention to the matter.

Mr. Casselman: Yes.

Robert Hiller (American Cyanamide): I do not agree with the suggestion that the user resin-catalyst system. Various systems are carefully worked by the resin manufacturer to give best results and should give best results when products designed to work together are used. On hardness of jell, does that determine quality of bond?

Mr. Casselman: Best to watch trim samples to keep track of trim time.

Mr. Hiller: Resin can have soft jell at one point and still give good bond.

M. L. Newton (Sylvania Electric): How about moisture content in cross banding. Important? Should it be kept to 6%?

Mr. Casselman: Variation is possible. Drier veneers make for better spread.

Mr. Newton: In cabinet work after 30 days we can see results of high moisture content.

Mr. Casselman: How does it show?

Mr. Newton: Knots may show through in 30 days.

Mr. Casselman: We condition doors, which aren't as critical as your products.

George Elliott (Rohm and Haas Co.): I'd like to emphasize my feeling that catalysts designed for individual manufacturers glue are better technically than using ammonium chloride with all. You are certainly not getting the most from each manufacturers product.

You verified the truth of this statement when you said that on special or tougher jobs, the glue manufacturer should be contacted. As to technical control, it is my firm belief that control testing should be done by a disinterested person, and by that I mean a person not responsible to the production foreman because these tests will always be colored in favor of production department. Quality control should be responsible to management, i.e. superintendent.

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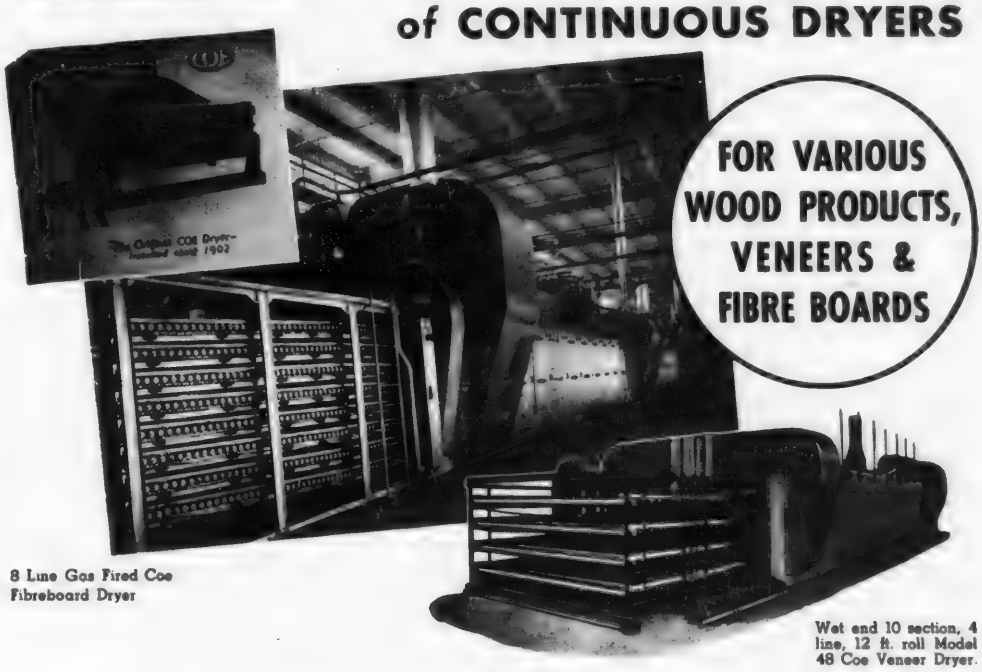

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BONDING METALS

(Continued from page 45)

(6) ——: Military Specification, MIL–A–927; Adhesive; Synthetic Resin (For Phenolic Laminates)

(7) ——: Military Specification, MIL–A–928; Adhesive; Synthetic Resin (for Clad Aluminum Alloy to Wood).

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Discussion

Richard Blomquist (Forest Products Laboratory): Metal is a problem to clean for gluing. Do metal people supply metal with prime sheet?

Mr. Tigelaar: Expensive but good if done.

Mr. Blomquist: It might mean less end cost.

Mr. Tigelaar: Zinc coated steel gives good bond; also for painting.

K. L. West (West Fabrication Laboratory): Can you give different types and methods in cleaning methods?

Mr. Tigelaar: (Please fill in methods.)

Mr. West: Metal men wouldn't do the cleaning job.

Mr. Blomquist: USFPL Bulletin 1813 A gives some chemical methods for cleaning. Acid is better where there is corrosion.

Mr. Casselman: What are limitations for gluing aluminum to wood?

Mr. Tigelaar: Very relative depending on moisture of wood—as temperature goes up there is more warpage unless flexible adhesive is used to take stresses.

Mr. Blomquist: Could cool under pressure.

Mr. Tigelaar: Stresses still exist.

Wayne Hutchins (Baker Furniture): Can brass be cleaned for gluing?

Mr. Tigelaar: Can be done well. Is done frequently in auto trade.

AMINO RESIN

(Continued from page 49)

M. M. Selbo: Comment on gap-filling phenolic resins for ply core doors glued in one step.

Detwiler: This is being done using ureas, but to the best of my knowledge it is not being done with phenolics. However there is no technical reason why it couldn't be done.

John Lewis (Hercules Powder Co.): A recent paper mentioned that urea resins could be cured at alkaline pH. We have been unable to duplicate this work satisfactorily. Would you care to comment?

Detwiler: I have seen this but have not tried to duplicate it. I would not expect good wood bonds using alkaline cured urea resins.

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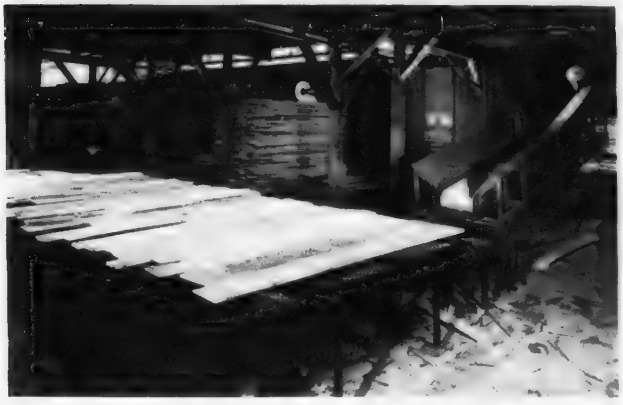

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G. A. Seidel (Splicewood): By what method does the fast clamping urea resin work?

Detwiler: The vinyl portion grabs at once and holds until the urea resin has a chance to cure.

A. R. Tegge, Jr. (Quartermaster Container Laboratories): Do the emulsion-urea resin blends or the emulsion type adhesives have favorable gap-filling properties?

Detwiler: No they do not.

G. C. Elliott (Rohm and Haas): Please compare anionic ureas, cationic ureas, and cationic melamine wet strength resins as to retention of the resin in paper pulp and as to strength.

Detwiler: Retentions are in the following ranges: Melamine acid colloid 65–95%, anionic urea 30–60%, cationic urea 45–75%. The wet strength varies with a number of factors, but in general it is 20 to 50% of the dry strength.

E. A. Patton (Curtis Cos., Inc.): What factors influence the transparency of overlays in decorative laminates?

Detwiler: We believe the most important factor is the difference in refractive index between the resin and any other material present. It follows, therefore, that anything that reduces this difference in refractive index will improve transparency. Some important factors are: very good impregnation, so entrapped air is held to a minimum; overlay made of synthetic fibers having a refractive index that is close to that of the resin, use of optimum resin content in the overlay.

E. A. Patton: How does cure influence crazing of melamine overlay?

Detwiler: Crazing of the melamine overlay has been traced to a number of causes. One of the most easily recognized and corrected is overcure. High volatility prior to cure is the most common cause of crazing in melamine overlays, so I would check this before I would look for overcure.

DURABILITY

(Continued from page 57)

Mr. Selbo: The stresses will vary as the moisture content varies. Throughout the exposure cycles the joints or part of the joints may be subjected alternately to tensile strength or shearing stresses or a combination of both depending on whether the wood is shrinking or swelling.

Ralph Casselman (Paine Lumber Co.): How about mechanical fastenings?

Mr. Blomquist: Design of the joint determines whether to use to glue. We need better designed joints.

John Reno (Pacific Lumber Co.): Why the low values on block joints?

Mr. Selbo: You have, in effect, cross banded lumber in this joint, with resulting high stresses. Swelling and shrinking stresses would be very high in the block joints.

Mr. Snider: How would variation in clearances between dowel and mortise and tennon joints affect results?

Mr. Selbo: The clearances between the pin and hole was about the same for both types of joints.

L. Spiwak (Snyder Chemical Corp.): In consideration of the different conditions present in each type of joint, especially as regards grain direction, were the adhesives specially formulated as to obtain optimum performance for each type of joint? If not, to what extent would such modifications of the glue formulations affect the test results?

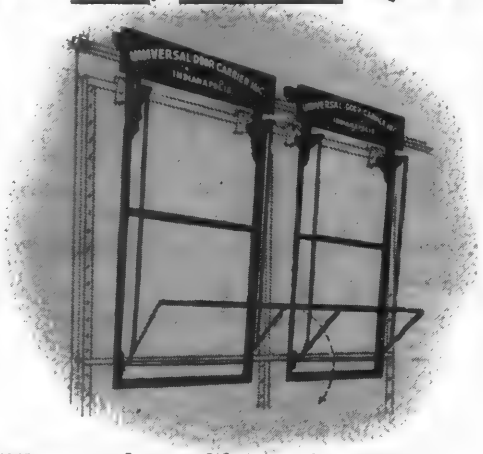
Mr. Selbo: I cannot say to what degree but it is entirely possible results could be affected to some degree.

MESQUITE

(Continued from page 71)

wafers are trimmed on the edges into various patterns by the use of a cleverly-designed machine. This block flooring may be laid quickly and economically in mastic over concrete

For Fast, One-Man Operation of Dry Kiln Doors



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floors. Checking of these cross-section blocks upno seasoning does not present any problem because of the small difference between radial and tangential shrinkage. Shake occurring across the center of the cross-sections may be filled in during finishing. This defect might possibly be used to advantage through "romancing" the wood in applied sales psychology (Fig. 8).

Furniture, novelties, etc.: Mesquite wood may be used to make furniture, picture frames, ash trays, pipe bowls and various novelties. Inasmuch as sawlogs are limited in availability, there is little opportunity to use mesquite for such items as furniture. Small novelty industries might be developed using mesquite wood.

During World War II, mesquite wood was tested for shuttle block material for use in the textile industry as a possible substitute for dogwood and persimmon. However, mesquite wood appeared to be unsatisfactory for such use.

Conclusions

With respect to the various mesquite utilization possibilities as discussed in this paper and at the same time recognizing the limited research on the subject to date, there are two products which appear to offer some commercial possibilities. These are: (1) charcoal and (2) block flooring. In addition, a hardboard produced from the whole tree by a semi-wet process appears worthy of further exploration.

Mesquite charcoal is of good quality and appears suitable for use in charcoal grills as well as in the manufacture of steel.

Hexagon and other shapes of mesquite block flooring capable of being produced by mass production methods from bolts four to eight inches in diameter holds promise for extended use as a serviceable covering for concrete slab floors. Modern architecture with its emphasis on low one-story homes has swung to extensive use of concrete slab floors resting directly on the ground. This opens a possible market for mesquite block flooring.

Hardboard may be produced from the whole tree at low cost. Land clearing equipment now in use bunches the tree and shrub forms for burning. Instead of burning, portable chippers may reduce this material for use in the manufacture of a suitable hardboard for interior use—such as closet linings and garage ceilings.

Discussion

V. B. Volkening (Dow Chemical Co., Freeport, Texas): What is the difference between Mesquite and Huisache?

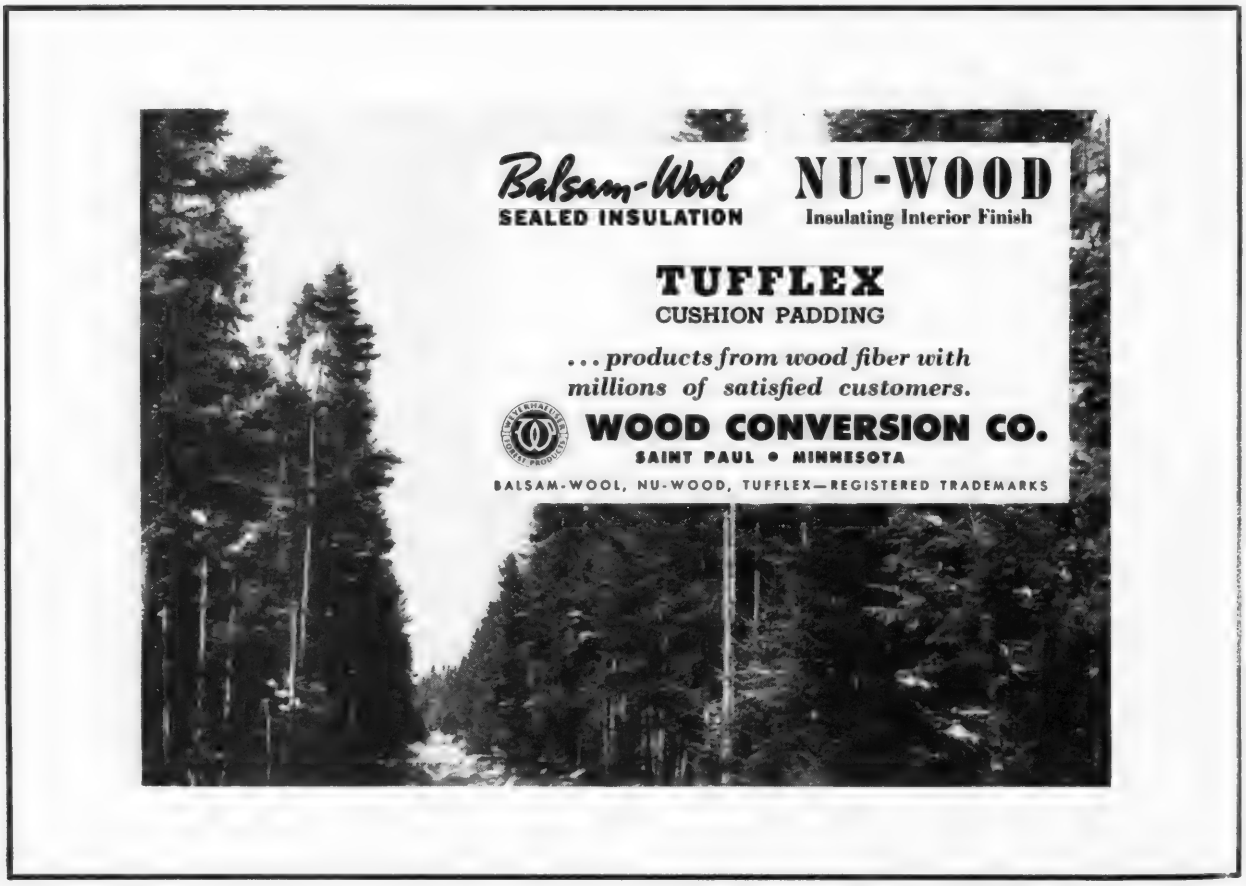
Mr. Marshall: They are two entirely separate species. I do not have any data on the properties of Huisache.

Russell K. Hallberg (Bowaters Southern Paper Corp., Kingston, Tenn.): What is the growth rate of mesquite?

Mr Marshall: It varies considerably and it is sometimes very difficult to count the growth rings. It will grow as much as 1/10 inch per year in radius under favorable conditions. Past records indicate that some trees have reached 3 feet in diameter and 80 feet in height. One tree that I know of was 10 inches in diameter at 104 years of age. Over most of the mesquite range, however, both diameter and height growth are of slow rate.

W. L. Meek (University of Illinois): Is gum produced and collected from Mesquite?

Mr. Marshall: Some gum has been produced but I do not know of anyone now collecting it commercially. It can be used for pharmaceutical and other purposes.



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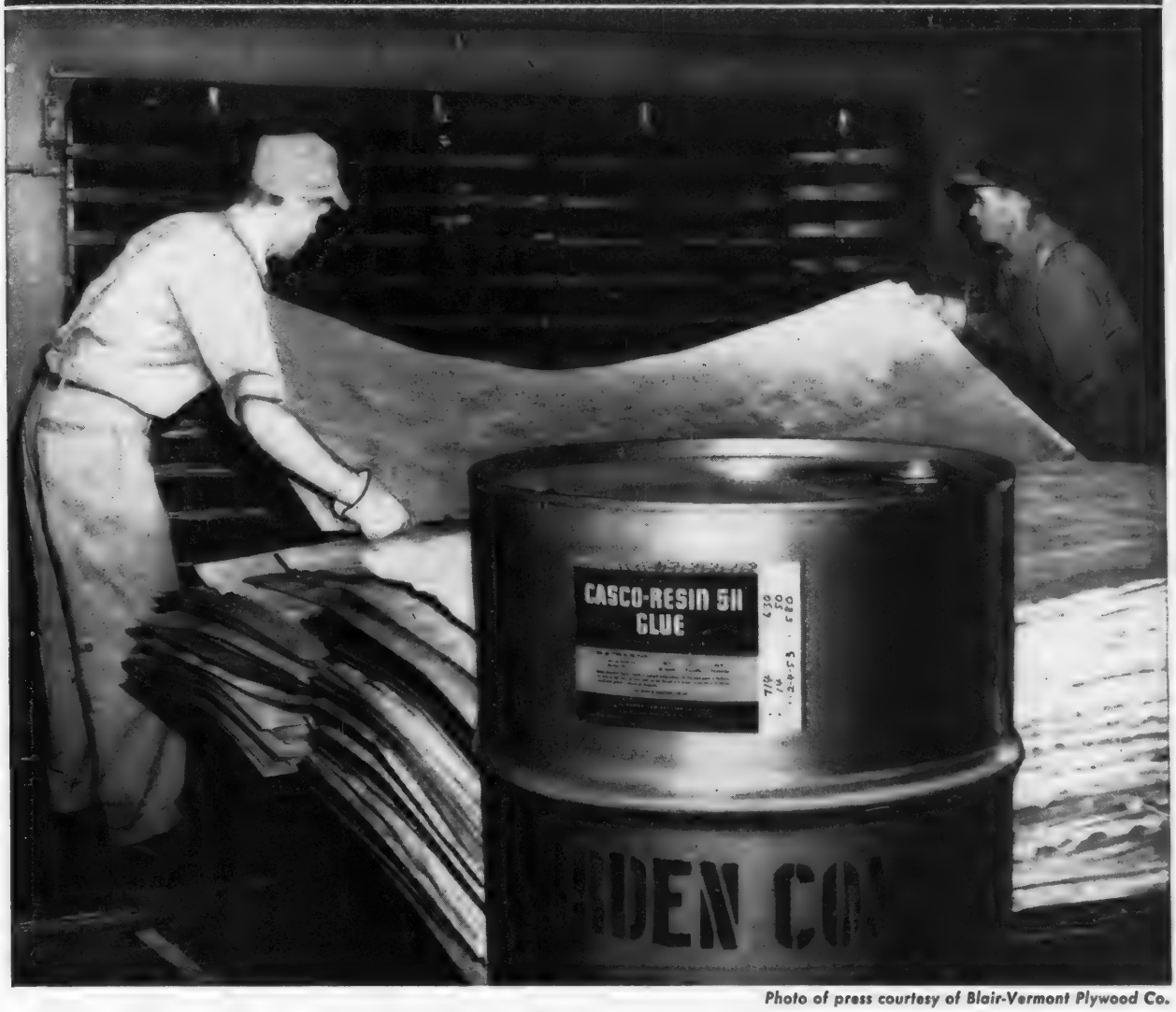

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INDUSTRIAL ADHESIVES DEPARTMENT

THE BORDEN COMPANY

Chemical Division

DESIGN DATA

(Continued from page 94)

mens. Is this difference characteristic of both cylinder and fourdrinier boards?

Mr. Kellicutt: Yes, this directional difference is apparent in both types of board but it is most pronounced in cylinder boards.

Ross V. Martin (Sears Roebuck & Company, Chicago 7, Illinois): Are the moisture-strength and moisture-pickup characteristics of fiberboard similar to those of wood? Is the E.M.C. of fiberboard the same as that of wood at a given temperature and relative humidity.

Mr. Kellicutt: The fundamental relationships are the same. Both materials are hygroscopic and are less strong, in general at higher moisture contents. The E. M. C. values of the two materials follow the same pattern through variations in temperature and relative humidity and, under any given set of conditions. The E. M. C. of fiberboard is generally lower than for wood.

A. R. Tegge, Jr. (Quarter Master Container Laboratories, Chicago, Illinois): Regarding the scatter of the points seen in figure 4 (showing relationship between compressive strength of a box and the dead load that will cause failure), what was the range in relative humidities to which the boxes were exposed? Does this account for some of the spread?

Mr. Kellicutt: Controlled exposure conditions ranged from 80° F. and 30% R.H. through 80° F. and 90% R.H. Six exposure conditions within this range were used. Much of the spread is probably due to the fact that the boxes subjected to the actual stacking loads were not the same ones used to derive the machine test load. The use of matched boxes was necessary because those tested in the machine were broken and were not suitable for use in the dead load phase. Small variations in physical characteristics between matched boxes, therefore, could be expected to produce such a spread.

R. B. Deacon (Signode Steel Strapping Company, Memphis, Tennessee): Does the influence of moisture content upon box strength differ materially between flute sizes (A, B or C flute) or between solid and corrugated board?

Mr. Kellicutt: No. As the moisture content fluctuates within a given range the effect upon the strength of each of these types of board will be similar. Assuming, of course, that all boards are made of the same materials.

Robert R. Ferrell (Kennedy Car Liner and Bag Company, Shelbyville, Indiana): Are the results of the studies you have conducted at the Forest Products Laboratory available to the public?

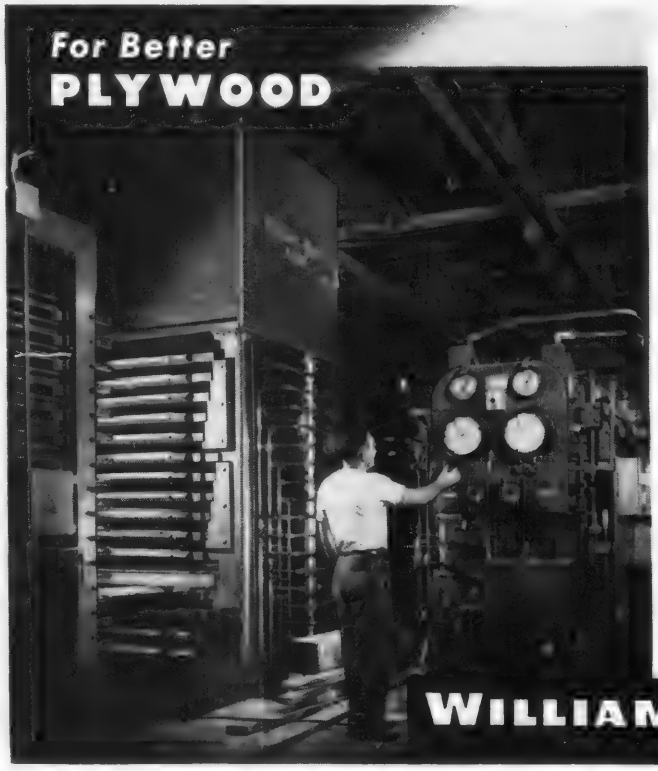
Mr. Kellicutt: Yes. Address your request by report number or title to: Director, Forest Products Laboratory, Madison 5, Wisconsin.

Mr. Sands: Do standards exist in industry to guide the fabrication of fiberboard.

Mr. Kellicutt: Yes.

John M. Ladd (General Box Company, Des Plaines, Illinois): The boxes, or tubes, used in this test were empty. Would the results differ materially if the boxes had been loaded?

Mr. Kellicutt: This would depend, of course, upon the type of load. Some loads actually support the container while others depend upon the container for protection from external forces. For that reason empty containers alone were evaluated in this study.



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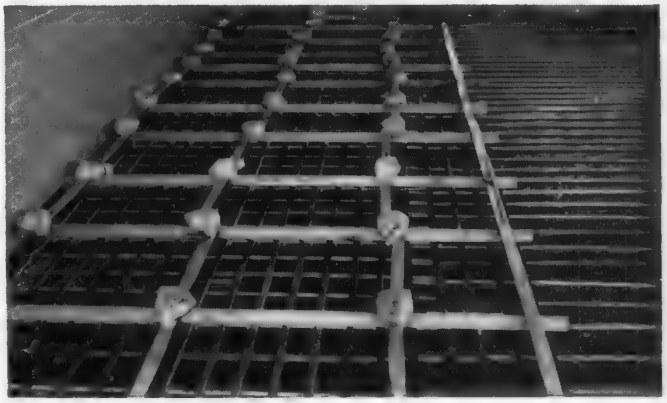

Understripping of gym floor, as well as white-pine door frames, was pressure-treated to a 6# retention of penta solution.

Penta has wide usage possibilities. It is specified regularly by utilities, railroads, in heavy construction and in farm and home building.

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FREE FILMS OF PAINT

(Continued from page 125)

vapors of the solvents come in contact with the paint. Swelling of a coating in excess of any swelling of the wood does, then, tend to cause blistering if at the same time the paint film is softened, plasticized, and perhaps its adhesion to the wood weakened. There is no reason why water should differ from other swelling solvents in bringing about paint blistering.

Ross Martin (Sears Roebuck): What effect of flow or gravity in making samples?

Dr. Browne: Effect is not Newtonian—must be brushed on.

FACTORS AFFECTING

(Continued from page 134)

Discussion

Roy M. Carter (North Carolina State College): How do you measure the thickness of film on wood panel?

Mr. Blackmore: A metal panel is placed along side the wooden one and sprayed simultaneously. Film thicknesses are measured by conventional methods on the wood panel.

G. G. Sward (Paint Ass'n): What would be effect if time between cycles were extended?

Mr. Blackmore: If the lacquer film tends to become embrittled on aging, the test will show it. Using the test on freshly applied films as well as on films aged for various lengths of time, the aging characteristics of the film can be determined.

Ross Martin (Sears Roebuck): On test panels does grain in copper make any difference? I notice that, although when pressure is applied the bulb expands equally but all checks are in the same direction. Why?

Mr. Blackmore: In the case of this particular specimen the directional cracking is probably due to the stresses set up because of flow lines. This lacquer may have had very fast solvents that did not permit uniform flow-out. I am sure that grain in the copper sheet was not a factor. As shown in the slides, most films shatter in all directions or in concentric rings.

FILLER

(Continued from page 138)

tunnels, excellent filling can be obtained on comparatively short drying schedules with adaptations of the old overnight-dry type of filler. It is believed that intensive research and development work on fillers is now being carried on by many manufacturers of finishing materials.

In considering the proper drying of filler, it is necessary also to take into account the coating which is to be applied over it. A sealer or lacquer with a normal composition of solvents should, when applied, wet into the top surface of the filler in the pores of the wood. This action, assuming that the filler has the proper color and strength of color, will produce a sharp, clear pore color. If the filler has dried too hard or if the solvents in the coating are too weak, a lack of bonding at the interface will result in gray or shiny pores. If, on the other hand, the filler is not sufficiently dry, or the solvents in the coating are too strong, a puffing or heaving of the filler will take place. This is often confused with "orange peel" in the coatings. Many times lacquers or sealers have been condemned for poor flow or "orange peel", when the fault was improper drying of the fillers.

A method of visual comparison of filling results, which was developed by Messrs. John Whiteside and Richard Tuttle of The Lilly Company, is illustrated by Figures I and II. These are photographs of plaster casts made of two similar oak panels which had previously been filled and coated with

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lacquer sealer. These panels were selected as being of hard-to-fill type of wood, having large and deep pores.

On the plaster cast, the depressions in the surface of the filled panels protrude above the flat surface of the cast. These protuberances are accentuated and made easy to see by fogging a thin mixture of black lacquer with a spray gun held nearly parallel to the surface of the cast, and thereby creating a shadow effect.

Figure 1. represents a panel filled by methods which are more or less normal procedure in many finishing rooms. Figure 2. represents a panel filled by the double application and padding method described above.

In conclusion, while there still may be many advancements to be achieved in producing better fillers, particularly of the quick-dry type, it is the writer's belief that the filling job in most finishing departments can be improved with present materials. To do this will require careful preparation of the surfaces to be filled; close attention to the details of the jobs of applying, padding, cleaning up, and drying of filler; careful and intelligent inspection; and, finally but not least, an appreciation of the importance of filler department by the management.

PROCESS HARDBOARD

(Continued from page 148)

Water

A glacial fed stream is used as a source of process water with a make-up on maximum production of 300–500 gpm. Wastes are discharged directly into the stream and are periodically checked by the State Sanitation Commission. The B.O.D.'s of such waste have in no way been detrimental to aquatic life. We have found, however, more loss of solids than desirable, so are now setting up equipment to recover the solids, which will be returned to the system for reuse.

Freeness of Stock

The presence of bark has in no manner caused a slowing of the stock in felting. On the other hand, recent laboratory work now being edited will show that the presence of the bark adds to the freeness. This has also proven out in commercial operation.

Summary

Mill scale production of hardboard from the wood by-products of an existing sawmill has demonstrated the suitability of an integrated operation for the production of a quality product. This process uses the bark to enhance physical properties of the product as well as to save valuable chemicals, and thus opens a new field of raw material to the wood processing industry.

HIGH SPEED

(Continued from page 169)

"fire ball" unit and brag about the good runs they make. Never have I seen them resent the speed in a well-designed plant.

Unless you have proper supervision, high speed production can become a pitfall. You can probably bank on cutting your cost of production, but you haven't gained a thing unless you have maintained your quality and are able to sell all the increased product. The rules of the National Oak Flooring Manufacturers Association require that, in case of reinspection, the National Inspector is to rule in favor of the customer if his reinspection indicates that the shipment is more than 5 percent off-grade. Stated another way, this means that you must make flooring that is 95 percent perfect, or else you are not doing a "quality" job. Obviously, then, you have not benefited if, in attempting to increase production

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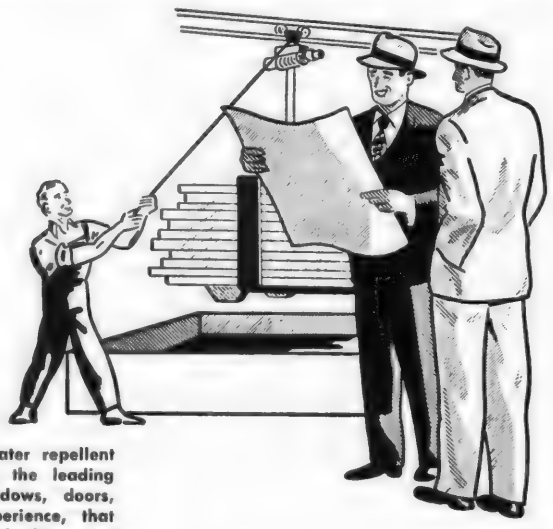

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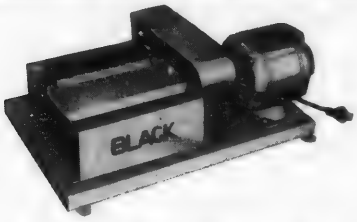

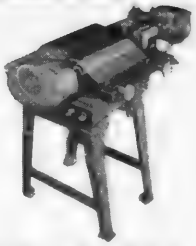
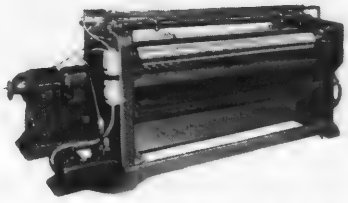

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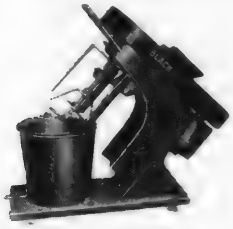
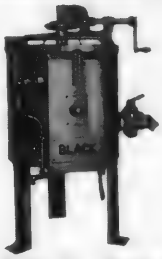
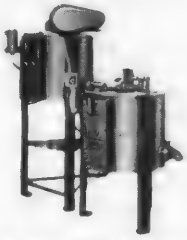
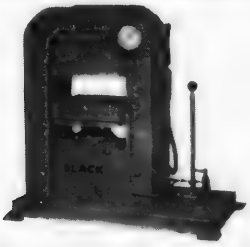
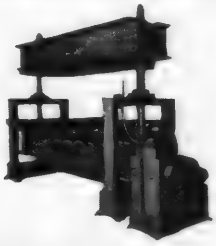
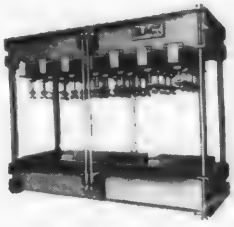





GLUE MIXERS AND HEATERS FOR EVERY REQUIREMENT

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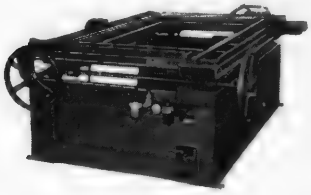
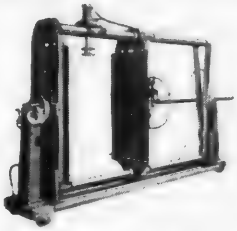
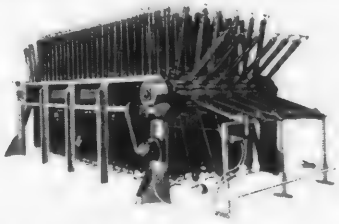

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materially, the standard of quality is not maintained.

The point has been argued that high speed production may be fine in a "sellers market", but what will happen if demand decreases. As I see it, in poorer times it is only a matter of degree whether you have to sell the production of a fast or a slow unit. If you can maintain full employment with a slow unit, the chances are you might be better off with a fast unit that would make the same flooring in less time and let you use the crew in another part of your operation instead of maintaining 2 separate crews. We are presently building flooring units that will run fast or slow as required, so the question is rather academic with us. More important is to remember that, fast or slow, there is no easy way to make hardwood flooring. A rough-hewn instructor once said during a class on steam engineering, "Now remember gents, don't never at no time under no circumstances start no turbine without you got plenty erl in the bearings." I suspect that it was his complete butchery of the English language that caused me to remember his exact words all these years. I would like to paraphrase his words as follows: "Remember, gentlemen, don't never at no time under no circumstances start no high speed flooring plant without you got plenty patience and a good crew."

Discussion

T. C. Weill (Carboloy): With respect to your comment on brittleness of carbide tips, we have sold thousands of blanks for use as jack hammer bits for breaking rock, concrete, etc., and in this application shock encountered is extremely high. One machinery manufacturer recently told me of a pressure bar on a planer that was jammed into a cutterhead of carbide planer knives. He said that upon examination the pressure bar had chunks gouged out of it, but there were no chips in the carbide knives as a result of the accident. There are specific grades of carbide for various woodworking application. That is why we encourage tool manufacturers to work with us to develop the best carbide tools for each application.

Mr. Miller: I referred to carbide tools as being brittle and I realize that I should have phrased myself more clearly. What I was trying to say was that the brazing of the carbide teeth is brittle and contributes the weakest part of a carbide tool in that the carbide teeth fall out if the brazing gives way.

G. M. Mitchell (Brammer Manufacturing Company): We use carbide tools exclusively. They have been giving us big savings on plywood with high speed cutterheads. Very useful in the machining of plywood parts requiring mill-to-pattern bits.

RECOVERY

(Continued from page 182)

the proportion of 1:1 to the pentachlorophenol, and that its cost is 15 cents per lb. The total cost in the treatment with pentachlorophenol and vapor solvent recovery is about $4.00 per M. less than for the steaming operation, since there is no need for using the anti-blooming agent if the wood is processed by Vapor Solvent Recovery. Again it will be seen that the air drying is the most expensive because of the loss of solvent.

Commercial Operation

Figure 8 is a photograph of the first commercial plant constructed for Vapor Solvent Recovery of treated lumber. This is the plant of the Brice Wood Preserving Co. at Archer, Fla. which employs Vapor Solvent Recovery on copper naphthenate treated wood. The cylinder shown has a capacity of 8,000 FBM.

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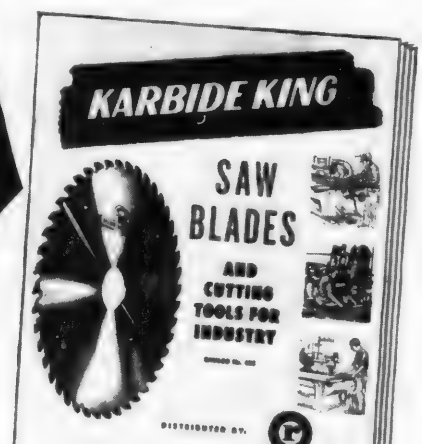

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☐ Please send name of nearest Karbide King dealer.

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HYSTER®

EQUIPMENT for the Forest Products Industry

HYSTER

Literature Cited

(1) Hudson. FPRS Proceedings 1: 124, 1947.

(2) —— AWPA Proceedings 46: 209, 1950.

(3) —— U. S. patent 2,435,218; February, 1948.

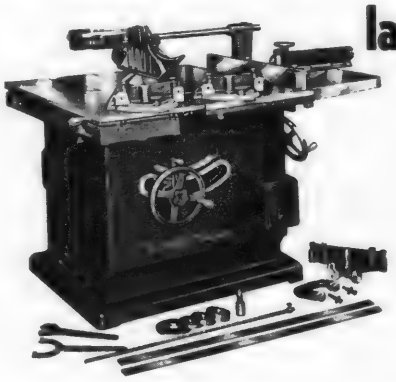
Discussion

James A. Greenwald (Cuprinol Division, Darworth, Inc.): One benefit of this process should be emphasized: After treatment the wood can be laminated with no further processing as is required by other methods of treatment. This advantage seems to be due to the scouring action of the solvent on the surface of the lumber.

Jacob B. Huffman (University of Florida): What are the strengths of the solutions used in the treatments?

Mr. Hudson: 9¼ per cent for Copper Naphthenate, and 9–10 per cent for Penta. If the wood is treated to a retention of ¾ of a pound per cubic foot, ¼ of a pound per cubic foot of Copper Naphthenate is extracted with the solvent: or ½ pound per cubic foot of Penta will be extracted with the solvent.

This "Oliver" Saw Bench will simplify the handling of large panels . . . and reduce cost



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The saw arbor tilts up to 45° to permit the operator to rip, cross-cut, miter or dado while the work remains flat on table. An 18-inch saw projects 4¾" through table which has 4¼" vertical movement. Rips up to 50"; cross-cuts 48" by 1" thick. Fitted with the most accurate and complete set of graduated gauges. Write for Bulletin 88-D.

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1953 National Meeting

(Continued from page 7)

Advisory Committee, Executive Board Meet Jointly

On Monday noon, the FPRS Section Officers Advisory Committee, representing 13 sections from Southern California to Eastern Canada, met with the Executive Board to recommend additions and improvements in the conduct of Society affairs. The Board met subsequently to review and enact a number of their suggestions calling for new membership directories, representation at various industry meetings, review of National office functions, review of Society policy on release of author papers, strengthening of subject matter committees, and other matters.

Glues and Gluing Technology

Ralph Casselman, assistant to the vice-president, Paine Lumber Company, Oshkosh, Wis., discussed "Production gluing." He pointed out how careful technical control of glue-room operation pays off in dollars and cents.

The second paper was jointly prepared by J. G. Kuenzel, senior materials engineer, Materials Development Division, Wood Products, Bureau of Ships, Navy Department, Washington, D. C., and N. V. Poletika and H. B. McKean, Assistant and Associate Directors of Research, Timber Engineering Company, Washington, D. C. The title was "The gluing of preservative-treated wood for severe service conditions." McKean, in response to questions from the floor, said the industry's laminated truck bodies are standing up under rigid testing.

A new trend in the gluing of wood was discussed by Jacques H. Tigelaar, Director of Research and Tests, Haskelite Manufacturing Corporation, Grand Rapids, Mich. The title was "Techniques for bonding metals and plastics to wood."

A short history of the development of synthetic adhesives was given by Earl B. Detwiler in his paper, "Properties and application of amino resin adhesives and binders." Mr. Detwiler is a group leader in the Development Division, American Cyanamid Company, Stamford, Conn.

Concluding paper in the first day's session was one by M. L. Selbo, chemical engineer, and W. Z. Olson, technologist, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wis. Their paper, which dealt with 11 different glues and seven types of joints common in assembly of furniture, was titled, "Durability of woodworking glues in different types of assembly joints."

As a special feature of this session, James Rice, junior at Alabama Polytechnic Institute, presented a resume of his prize winning undergraduate paper entered in the Wood and Wood Products Award contest.

The Glues and Gluing program was arranged and directed by Alan A. Marra of the School of Natural Resources, University of Michigan.

Successful Table-Top Exhibit

Monday evening was set aside for members and guests to visit the 54 "table-top" literature exhibits by supplier companies and educational and research institutions. The exhibits, on display all three days of the meeting, illustrated many of the latest techniques, materials and facilities available to the industry. The names of the exhibitors are found later in this report under "Paul Bunyan Hour" sponsors.

Chemical Utilization and Packaging

At the Tuesday morning technical sessions, members heard four papers on chemical utilization of wood and five papers on various developments in the packaging and crating industry. Two speakers reported development of a crating material that combines wood veneer with glued-on paper facings. The material is said to provide a stronger, more protective crate while making possible better utilization of our forest resources.

The first paper in the chemical utilization group was titled "Pulp and paper: tools for hardwood utilization", by J. N. McGovern, chemical engineer, Forest Products Laboratory. Mr. McGovern pointed out how new and expanding pulping processes afford a rapidly growing outlet for second-growth hardwoods that stand in the way of the regrowth of the more desirable softwoods in the South and throughout the Nation.

"Wood in a Gulf Coast chemical plant" was presented by V. B. Volkening, Group Leader, Chemical Division of the Dow Chemical Company, Freeport, Texas. A striking feature of Mr. Volkening's paper were the examples of replacement of steel structures by wood in a number of locations where steel was unsatisfactory because of rust or corrosion.

N. Levitin and H. Schwartz, Research Chemist and Laboratory Superintendent respectively, Ottawa Laboratory, Forest Products Laboratories of Canada, showed the results of their research on "Delignification of spruce sawdust with chlorine dioxide" in efforts to derive the rayon type of cellulose from sawdust and thus develop a use that would not be hampered by the normal shortness of fiber found in this form of wood residue.

"Potentialities of chemical utilization of wood" was the title of a paper by A. S. Gregory and Dr. A. K. Esterer, Development Department, Weyerhaeuser Timber Company, Longview, Wash.

Leading off in the container discussions, K. Q. Kellicut, engineer, and E. F. Landt, technologist, U. S. Forest Products Laboratory, presented the subject, "Basic design data for solid shipping containers." They presented a formula for predicting the strength of fiber boxes under various shipping and storage moisture conditions and a handy circular-slide-rule type of calculator to facilitate the designing and specifying of fiber containers for product and storage requirements.

John M. Ladd, Manager, Design and Testing Laboratory, General Box Company, Des Plaines, Ill., gave a paper titled "Research and design in the packaging field."

"Wood fiber felts for protective packaging", a discussion of the design of cushioning materials with specified resilience for a wide range of products, was handled by E. O. Lieberg, Manager, Industrial Sales Engineering Department, Wood Conversion Company, Cloquet, Minn.

A paper followed which described a container material composed of a single ply of veneer bonded between two sheets of kraft paper. A. L. Whiton, sales manager, Chicago Mill & Lumber Company, was the author—the title of his paper "Craveneer as used in the packaging field".

Another new product, made by bonding two sheets of kraft board on either side of a sheet of "distended" veneer was described in the paper "Ply-veneer shipping containers", by J. R. Roberts, Manager, and A. M. Fiskin, Project Engineer, Development Center, Weyerhaeuser Timber Company, Longview, Wash.

New Officers and Board Members Announced

At the official FPRS luncheon Tuesday noon, the Society's newly elected officers were announced by the Tellers Committee and introduced by the President. Announced were Robert D. Pauley, Weyerhaeuser Timber Co., Tacoma, Washington, president; Lester J. Carr, L. J. Carr Co., Sacramento, Calif.,

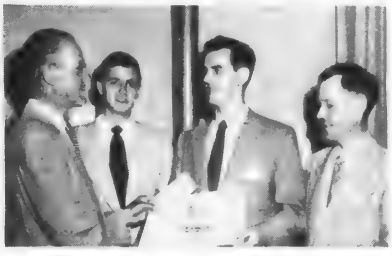
president-elect; Moss B. Christian, Chicago Mill and Lumber Co., Tallulah, La., vice-president; W. Jeter Eason, Nickey Bros., Memphis, Tenn., South Central Regional Board Member; and E. S. Harrar, Duke University, Durham, N. C., Southeast Regional Board Member.

Congressman Addresses Luncheon

U. S. Representative Harris Ellsworth (Ore.), feature luncheon speaker, praised wood research men for the forward strides they have made but pointed out the industry suffers from the time lag between the time materials and processes are developed at the research level and the time they are adopted by industry (see page 11).

Wood and Wood Products Award

Special feature at the noon luncheon was presentation by Jack Koellisch,



Jack Koellisch, James Rice, Eric Ellwood, and R. W. Wellwood.

publisher, of awards and certificates to two student winners of the Wood and Wood Products essay contest. Graduate honors went to Eric L. Ellwood of Melbourne, Australia, for his paper, "Effect of Temperatures and Moisture Content Upon Strength and Elastic Properties of Beech in Tension, Perpendicular to the Grain". He prepared his paper as a graduate fellow of the Yale University School of Forestry. Undergraduate winner was James Rice, Birmingham, junior at Alabama Polytechnic Institute School of Forestry at Auburn. Title of his paper was "Effect of Loading on Glue Line Strength."

At afternoon sessions one group of experts reported on latest techniques used in producing the fine finishes put on today's furniture and other wood products; while another group of speakers was detailing late developments in the manufacture of wood composition board, which is used for everything from subflooring to kitchen cabinet construction in the modern home. Shavings, chips, slabs, limbs and even bark, materials that formerly went up in waste smoke, were reported as used in manufacturing the multi-purpose boards.

In the afternoon session on wood finishing, Dr. F. L. Browne, chemist, Forest Products Laboratory, opened with a paper entitled, "The absorption of water, swelling and solubility of free films of paint." This paper reports basic laboratory research that has been badly needed to explain the behavior of paint on wood.

"Sanding wood for finishing" is the topic presented by O. B. Gordon, Products and Equipment Engineer, Behr-Manning Corporation, Troy, N. Y.

Other papers included "Factors affecting the integrity of a furniture finish" by Paul O. Blackmore, Director, Basic Development Laboratories, Interchemical Corporation, Finishes Division, Newark, N. J. and "Filler—the theory and technique of application" by R. S. Quigley, Development Engineer, Lilly Company, High Point, N. C.

The final paper on finishing was given by E. Sigurd Johnson, associate professor, Furniture Manufacture and Marketing, North Carolina State College, Raleigh, N. C. Prof. Johnson's paper, titled "Comparison of European and American Finishes", was based on an extensive tour of European furniture factories made by the author in 1952 and on his long-time familiarity with parallel American production facilities. Johnson noted low-cost European finishes are of very low quality.

The program and discussion on wood finishing was directed by B. E. Clatworthy, Radio Corporation of America, Indianapolis, Ind.

E. E. Matson, Chief, Forest Utilization Service, U. S. Forest Service, Portland, Ore., opened the discussion of wood composition board with "Potential raw material supply for wood fiber products."

E. A. Patton described the successful effort of the Curtis Companies of Clinton, Ia., to utilize in a particle board the wood residues resulting from their daily operations. The title of the paper was "Ponderosa pine woodwork residues for dry-formed particle board."

The production of hardboard from green unbarked slabs, edgings, and other chippable forms of sawmill residues was described in a paper by W. J. Runckel, Manager, Hardboard Division, Oregon Lumber Company, Dee, Ore., "Douglas fir slabs, edgings, and bark—wet continuous process hardboard."

H. C. L. Miller, President, Miller-Hofft, Inc., Richmond, Va., described the use of furniture factory residues in "Chipcore—its characteristics and production."

K. W. Guenther, Forest Products Engineer, Coos Bay Lumber Company, Coos Bay, Ore., discussed "Analysis techniques for hardboard pilot plant." This paper described the use of Unasort cards and standard quality control techniques to pin-point analysis and improvement of operations in hardboard development.

The program and discussions on wood composition board was arranged and directed by George G. Marra, Washington State Institute of Forest Products, Pullman, Wash.

Traditional "Paul Bunyan Hour" Sponsors

Late Tuesday afternoon, registrants took a brief respite from the series of technical meetings to attend the annual "Paul Bunyan" hour festivities. Contributors to the meeting and tabletop exhibits are the "hosts" at this traditional affair. It is estimated that well over 400 persons attended the event, and that the majority stayed for the FPRS Annual Dinner and entertainment which followed. Names of the Sponsors were on display during the Paul Bunyan Hour; were printed in the program; and are carried in the official records of the Society. They are as follows:

Mr. and Mrs. R. D. Pauley and Mr. and Mrs. Ken G. Chesley.

Yates-American Machine Company, Beloit, Wis.; Pacific Lumber Company, Scotia, Calif.; Rohm & Haas, Philadelphia, Pa.; National Casein Company, Chicago, Ill.; Perkins Glue Company, Lansdale, Pa.; Woodworking Digest, Inc., Wheaton, Ill.; American Manufacturing Company, Tacoma, Wash.; The Borden Company, New York, N. Y.; Rockwell Manufacturing Company, Washington, D. C.; Onsrud Machine Works, Chi-

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Tours of Memphis Plants

On the final day members divided their time between concluding technical sessions and visits to three of Memphis' best known wood products manufacturing concerns.

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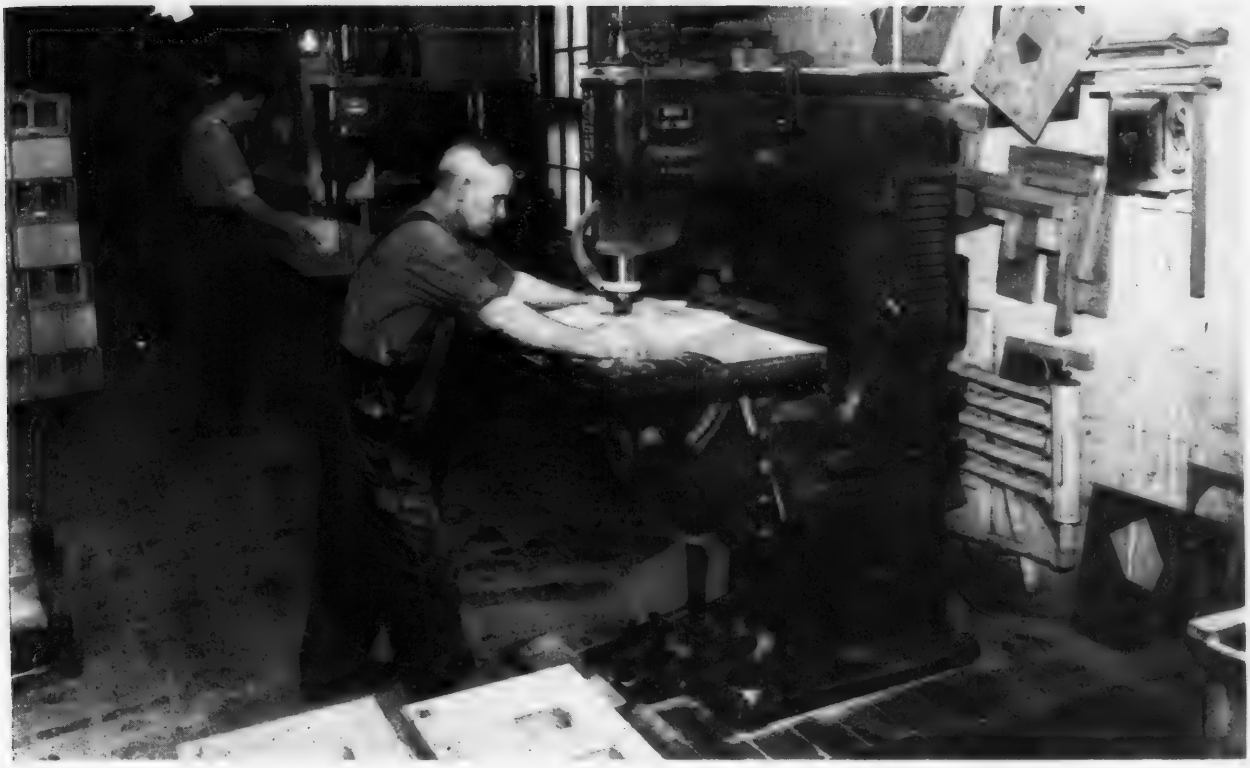

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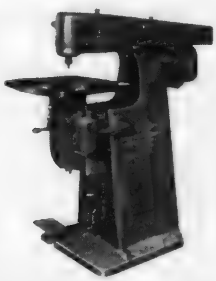
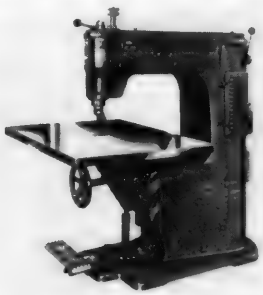
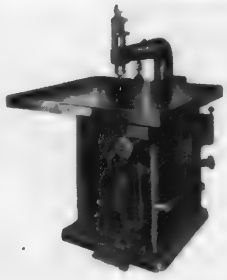


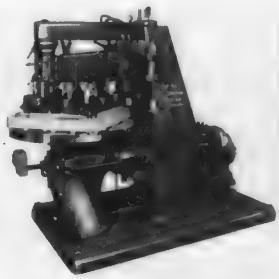
W-180 MEDIUM DUTY ROUTER



W-244 HEAVY DUTY ROUTER

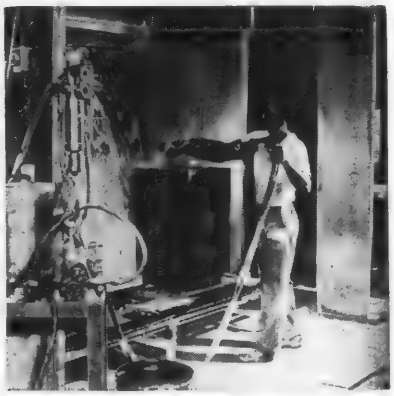


W-250 HEAVY DUTY SHAPER



WA-50 AUTOMATIC SHAPER

At the E. L. Bruce Company plant, 62 guests witnessed modern, high speed production of quality flooring that is used in homes throughout the nation. Seventy-seven persons visiting Nickey Bros.' plant saw facilities for turning out up to 60 million feet of face veneer per year. At both the above plants, the wide range of products as well as the high degree of utilization of the tree was of interest to the technologists.



Forty-seven persons visited the S. R. Hungerford Co., which in a short period of years has become the world's largest producer of solid mahogany furniture.

Thirty-three ladies registered for the meeting attended events on Wednesday which included visits to three famed private gardens in the Memphis area and a luncheon at the Chickasaw Country Club.

Wood Machining

The final morning technical session, arranged and directed by L. A. Patronsky, presented a group of papers on wood machining.

The opening paper was given by C. C. Chekouras, Manager, Cutterhead and Knife Department and Carbide Saw and Tool Department, Yates-American Machinery Company, Beloit, Wis. The title of the paper was "Designing cutterheads for maximum production."

C. E. Drake, President, Drake Corporation, St. Louis, Mo., discussed "Tungsten carbide can increase production."

Another interesting treatise on tungsten carbide tooling was given by Steven P. Koczan, Engineer, The Singer Manufacturing Company, South Bend, Ind., in his paper "Summary of the use of tungsten carbide tipped woodworking tools in regular production." Koczan compared overall costs between steel and carbide.

A Memphis man, Sydney R. Miller, Jr., Production Engineer, E. L. Bruce Company, wound up the session with his paper on "High speed production of flooring". Mr. Miller outlined the parts played in a high speed operation by the raw material, human element and machinery involved.

Preservation, Housing

The concluding session, Wednesday afternoon, was opened by Dr. R. H. Baechler of the U. S. Forest Products Laboratory with his discussion of "Effects of treating variables on absorption and distribution of chemicals in pine posts treated by double diffusion." The paper dealt with a simple, inexpensive wood treating method involving water soluble preservatives for fence posts that shows promise for treating construction lumber.

Monie S. Hudson, Research Chemist, Taylor-Colquist Company, Spartanburg, S. C. checked in with an interesting paper on "Recovery of organic solvents from wood pressure impregnated with solutions of copper naphthenate or pentachlorophenol." Mr. Hudson described means of recovering valuable treating chemicals and improving the utility of wood that has been treated.

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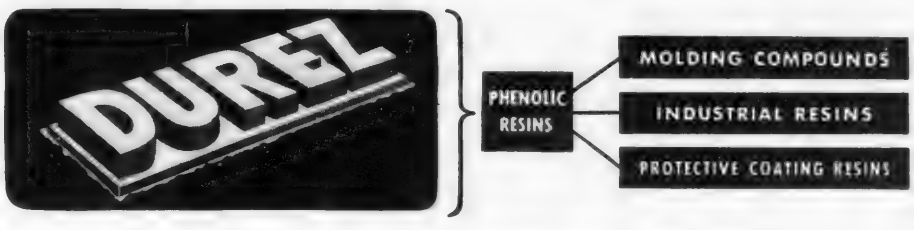

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"Air seasoning of California redwood" was presented by Victor H. Clausen, Engineer, California Redwood Association, San Francisco, Calif. This paper reported on studies by his association looking to the development of optimum spacing of drying yard piles using modern package handling of lumber.

Improved kiln drying schedules as worked out for two important southern hardwoods were described by John M. McMillen, Technologist, Forest Products Laboratory, Madison, Wis., in his paper, "Kiln drying water and swamp tupelo. Various separations by species and of sap and heartwood were suggested as well as measures for control of warping and casehardening.

George W. Stanley, Jr., General Manager, Rice and Adams Equipment Division, Pressed Steel Car Company, Inc., Buffalo, N. Y., described houses of plywood and lumber in his paper "Relocatable housing.—Some early history and a present-day example at Camp Stewart, Georgia," were cited.

A special feature of this session was the presentation by Eric L. Ellwood, Melbourne, Australia, of his prize winning graduate Wood and Wood Products Award paper.

The above session was arranged by Roy M. Carter, Chairman of the FPRS subject matter committees and professor at North Carolina State College, Raleigh, N. C.

The 1954 annual meeting of the Forest Products Research Society is scheduled for May 5, 6, 7, 1954 at Grand Rapids, Michigan. In conjunction there will be held the "1954 Woodworkers Industry Show" a full-scale machinery and supplier exhibit. FPRS is cooperating with the Show on arrangements. Non-members are cordially invited to attend both of these events.

Our Efforts Are Directed Toward Forests for Today and for Future Generations

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Report of 1953 Annual Business Meeting

THE SEVENTH ANNUAL business meeting, held in the Ballroom of the Peabody Hotel, Memphis, was called to order by President K. G. Chesley at 11:00 a.m., Monday, June 15, 1953. Approximately 75 members were in attendance.

1. Minutes of Previous Meeting

The preceding annual business meeting was held in Milwaukee, Wisconsin, June 24, 1952; and the minutes were published in the Dec. 1952 *Journal of FPRS*. No corrections or additions having been offered, it was moved, seconded and passed that they be accepted.

2. ANNUAL REPORT OF EXECUTIVE SECRETARY

This is the report of a year that has marked steady progress in F.P.R.S. affairs. In it are recorded briefly some of the principal developments and events, including actions of the Executive Board on matters of policy.

One of the most important milestones in this progress has been the steady growth of F.P.R.S. technical activities. During 1952, subject matter committees covering diverse, yet related fields, such as education, wood drying, glues, machining, wood finishing, quality control and wood composition board were activated. Through this kind of progressive technical activity, the F.P.R.S. is establishing a definite place in the scientific and economic fabric of the nation. When we consider the present instability of world peace. . . . . the dynamic changes which are taking place in living standards of people all over the world . . . . mass struggles of all nations for equality of economic, political and social opportunity . . . . and when we further consider the spiraling need for conservation of our own country's raw materials, it is clear to see how the Forest Products Research Society contributes an important basic service to our nation, by encouraging more research, and wiser utilization of our forests. The work of our many committees and that work demonstrated in our section meetings contributes to the welfare of our industry and our people.

Technical Activities

The real and full reports of F.P.R.S. technical activity will be written in the wealth of information uncovered here at Memphis in committee meetings and in the various publications and other meetings of the society. Credit for the phenomenal growth of F.P.R.S. technical activities belongs to the chairmen and members of such committees and to the men who have foreseen the need —former board member, Richard Hertzler, past president Roy M. Carter and our president, Kenneth G. Chesley. In addition to the established committees, 1952 saw the Executive Board endorse additional ones in the fields of packaging, logging and saw milling and mechanical utilization most of which are meeting this week.

To clarify F.P.R.S.' position in the function of establishing standards for any segment of the wood using industries, the Executive Board adopted the following policy: "The F.P.R.S. will not take an active part in having representation on any committee concerned with the establishment of standards or specifications except at the request of other recognized technical societies."

Section and Related Activities

Our six regions and thirteen sections have functioned well during the year. Total number of sections increased from 11 to 13 when the Eastern Canadian and Ohio Valley sections were chartered. Twelve of the thirteen sections have held one or more meetings during the year and one section, the Northeast, held four regular and extension meetings. It should be noted that one of the primary purposes of F.P.R.S. sections is to meet the requirements of the local forest products industries, as well as to advance the interests of the Society in such areas.

The accompanying table lists all twenty of the section meetings held during the year with notes on their features:

1952

April 15—Great Lakes Section, Grand Rapids, Mich.
April 23—Pacific Southwest, Los Angeles, Calif.
May 9—Northern California, San Francisco, Calif.
May 22 & 23—Northeast, York, Pa.
June 23, 24, 25—National Meeting, Milwaukee, Wis.
August 7—Midwest, Madison, Wis.
September 19—Ohio Valley, Louisville, Ky.
Oct. 9 & 10—Midwest, Clinton, Iowa
Oct. 17 & 18—Florida, Georgia, Alabama, Radium Springs, Ga.
October 28—Pacific Northwest, Vancouver, B. C.
October 31—Northern California, Sacramento, Calif.
Oct. 31 & Nov. 1—Great Lakes, Ann Arbor, Mich.
Nov. 7—Carolina-Chesapeake, Raleigh, N. C.
Nov. 7 & 8—Deep South, Baton Rouge, La.
Dec. 4 & 5—Northeast, New York, N. Y.
Dec. 8—Northeast, Jamestown, N. Y.
Dec. 9—Upper Mississippi, Wausau, Wis.

1953

Feb. 2 & 3—Pacific Northwest, Tacoma, Wash.
Mar. 5 & 6—Eastern Canadian, Montreal, Canada
Mar. 30—Northeast, Boston, Mass.

Time does not permit recognizing each of these meetings. Suffice it to say that they covered the area from southern California to Vancouver, British Columbia, and from Radium Springs, Georgia to Montreal, Canada, serving thousands of persons. President Chesley was a guest of honor or principal speaker at meetings in Milwaukee, Louisville, Clinton, Iowa; Baton Rouge, La.; and more recently in the Pacific Northwest. The important business of his own company required that in several cases he curtail plans to visit section meetings. First meetings of the society were held in a number of cities, among them York, Pa., Louisville, Ky., Wausau, Wis., Clinton, Iowa, Radium Springs, Ga., Sacramento, Calif., Ann Arbor, Mich., Jamestown, N. Y., Baton Rouge, La., and Montreal, Canada.

The Executive Secretary made several trips during the year, principally to contact advertisers but also to meet our members. Trips took him to the greater Chicago area, to Cincinnati, Louisville, Nashville, Memphis and St. Louis. On his major trip east, he visited with members in Atlanta, Asheville, High Point, Raleigh, Washington, D. C., Philadelphia, New York, Pittsburgh and Cleveland.

Sixth National Meeting

The Sixth Annual Meeting at the Hotel Schroeder, Milwaukee, Wisconsin, June 23, 24 & 25, 1952, was a success. During the 2½ days, 624 persons were registered, coming from 37 states, Canada and several foreign countries.

Publications

During 1952 the Society made great gains in its overall publication program, bringing to fruition the long awaited technical journal of the Forest Products Research Society, which was published at five intervals during the year, including the Annual Proceedings number in December. Late in the year the JOURNAL reached its present professional format. During 1952 plans were made and past publications were reviewed for the 19 loose-leaf "Wood Technology Series" booklets arranged by subject matter and which are on display at Memphis. The News-Digest reflecting the growth in F.P.R.S. activities was expanded from 4 to 8 pages per month with a corresponding increase in the amount of useful information contained therein.

Administration and Finance

The Executive Board met at three intervals during the year—Milwaukee, Denver and here in Memphis. Among important actions affecting the membership they voted to create a separate JOURNAL of the F.P.R.S. The first official issue of our own publication came out in April 1952. In September the Board voted to add a full time editor to the staff of the Society and to put the JOURNAL in the professional format we now have. Also in September the Board voted to incorporate and recognize the organization of the Section Officers Advisory Committee within the By-Laws of the Society. This action now gives the section officers an improved and more direct line to the Executive Board with their problems. It makes section officers everywhere a part of the national "team". In addition to setting up various technical committees, the Executive Board created and approved the Section Officers' Manual, which is issued to the sections for their guidance and growth.

The present Executive Office staff comprises the time of four full time and one ½ time persons. In addition, at various times during the year, we have employed other persons on a part time basis. What functions are performed in the Executive Office? First, we administrate and coordinate the activities of the national organization, its 13 chapters and 2,400 members. This requires an extensive record-keeping system and considerable correspondence with 10 executive board members, 82 section officers and trustees and 115 committee heads and members throughout the country. One of our staff members devotes full time to maintaining such records. Second, we promote income through the sales of advertising, publications and membership. One person devotes more than half of his time to the bookkeeping of the Society. Another works half days on filling publication orders, handling and maintaining advertising records, etc. Third, we publish and publicize F.P.R.S. activities. Our editor is concerned with the details of obtaining section and national papers, having them reviewed and getting them into print in our JOURNAL. He reviews a cross section of current publications, looking for news-worthy material for the monthly News Digest. From the public relations standpoint, the Society conducts a News Bureau—sending out news about the Society, its people and its activities to the trade magazines and the newspapers. In addition to these principal activities we perform many related duties, such as maintaining large mailing lists and rendering personalized service to many of our members and conducting an informal employment service.

Financially we started the 1952 fiscal year with a cash balance of $16,100 of which $12,321 represented prepaid 1952 dues and the remaining $3,598 represented accumulated surplus for a needed day in the future.

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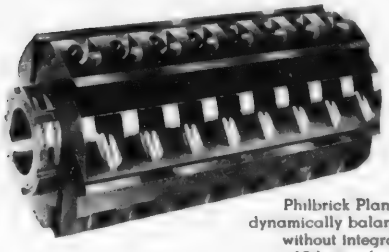

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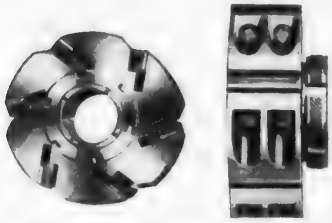

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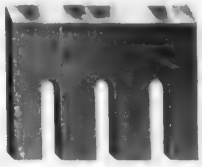

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During the year total receipts came to $83,384; total expenditures to $70,452. We entered the present fiscal year, April 1, 1953, with a cash balance of $29,033, of which $22,671 was prepaid 1953 dues and $6,088 was surplus. In other words, we made a net saving of $2,500 during the 1952 fiscal year operations.

Membership

During the fiscal year 1952 the net membership increased from 2,283 to 2,285 members. However, it should be noted also that this reflects also a net loss of 90 students offset by a gain of 92 voting, associate and supporting members. Since March 31, 1953 there have been 115 new members added to the rolls, bringing the total to 2,399 members—the highest total in the history of the Society. We now have members in all 48 states, U. S. possessions and in over 25 foreign countries.

Summing up it can be truthfully said that we have made important gains, both in the technical content and in the strengthening of administration during the Society year. We have again approached the new fiscal year with our Society on the upward cycle. The challenge to ensuing administrations is to keep that goal ever upward.

3. Report of the Audit Committee

The committee composed of Dr. E. G. Locke, Geo. Johnson and Chairman, Charley Thompson, met with accountants Victor Hobert and Dan Richmond, and the Executive Secretary, in Madison, May 20. It reviewed the fiscal year operating statement and balance sheet, comparing them also with those of 1951–52 and with the 1952–53 budget. It recommends in the future eliminating any valuation placed on printed matter of the Society in accordance with accepted practice.

The committee recommends the publication of Section financial statements in conjunction with the annual national report; as well as standardized Section accounting procedures including quarterly statements with certified bank balances. It recommends correct usage of the term, fiscal year. The period, April 1952-March 1953, is the 1953 fiscal year. It recommends that in the future more detailed operating statements be made available to the Audit Committee to include audits for previous and current year, and budget for pending year. Finally, it recommends that future annual budgets contain provision for both anticipated income and expenses of proposed national meeting for such year, improving budgetary control. Such budgeted item to be made up by Finance committee with subsequent changes proposed by National Meeting committee.

The committee pointed out the possible close legal relationship between national and section organizations, and suggested further examination into scope, limitations and responsibilities of each.

The report, and statements as published in the News-Digest, May, 1953, was made by Dr. Locke. On motion duly made and seconded it was accepted.

4. Appointment of Tellers Committee

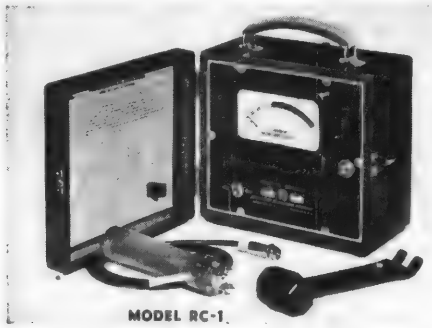
Pres. Chesley appointed: Ira Hatfield, R. G. Lennox, A. J. Panshin, S. D. Pryce, C. F. Van Epps, C. White, and G. A. Garratt, Chairman.

5. Proposed Constitutional Amendments

The Executive Board in session in March, 1953, recommended two amendments. Notification was mailed to all voting members. It was proposed that Article V, Section 3, be changed to read,

"Article V, Section 3 . . .

Dues for voting and associate members shall be $15.00 per year,



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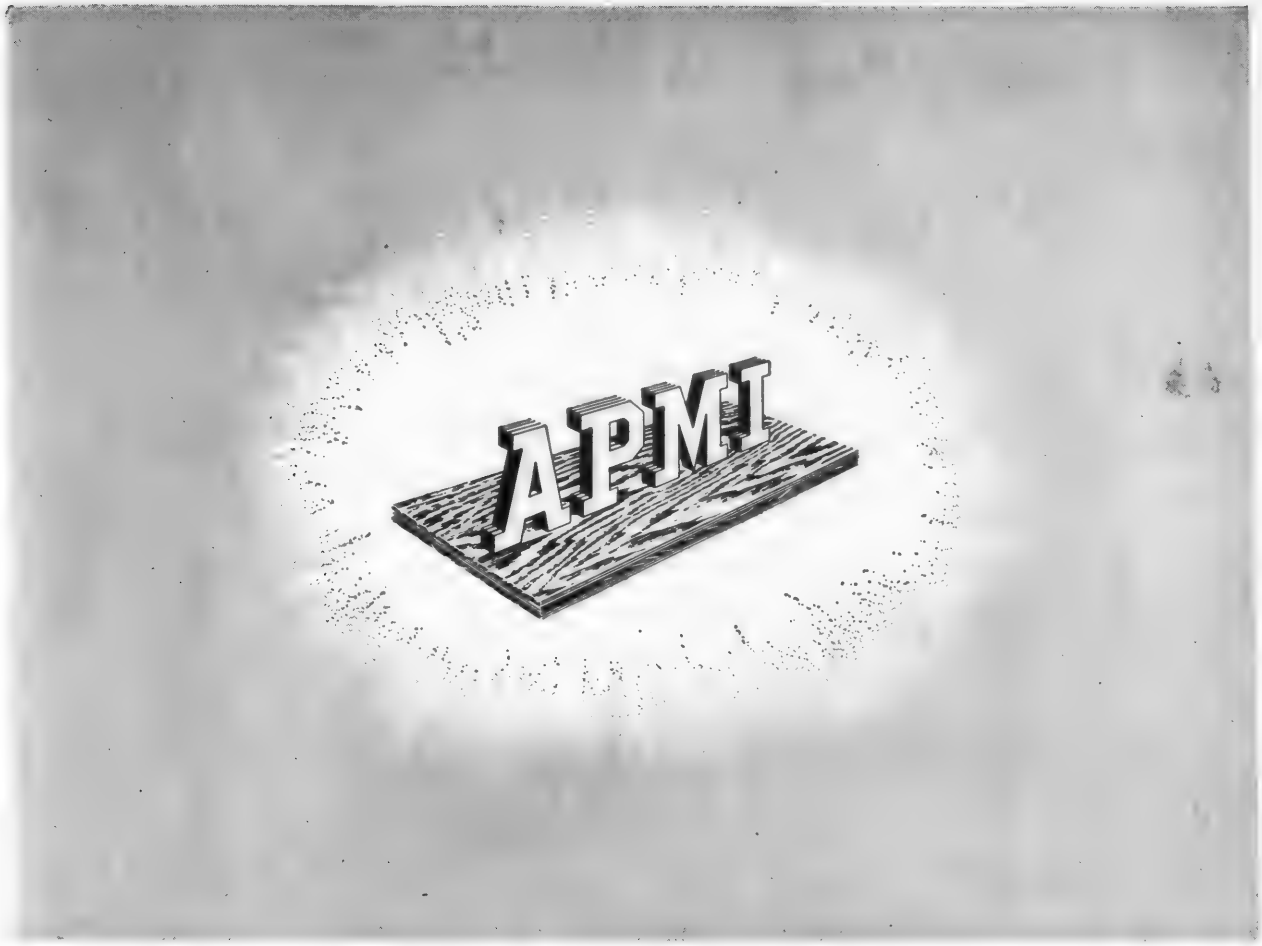

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$2.00 of which will be returned to the Section to help defray administrative expenses. Annual dues for the fiscal year will be due and payable on or before April 1 of each year. Voting and associate and student members joining between January 1 and April 1 shall automatically be members for the next fiscal year. Voting, associate and student members joining up to and including December 31 shall receive all publications to which they are entitled of that fiscal year."

"Article V, Section 5 . . .

The annual dues for student members shall be $3.00 per year."

The proposed amendments would, (1) eliminate an inequitable and clerically unwieldy provision for electing to pay for ½ membership late in the fiscal year, and (2) eliminate restrictions on student publication services in the event that the Executive Board voted to extend broader services to students.

Dr. Locke moved, duly seconded that proposed amendment, Article V, Section 3, be further amended to add the phrase underscored, ". . . shall receive all publications of that fiscal year *to which they are entitled.*" This amendment is necessary because at present students do not receive all publications of the Society. Motion carried.

On motion duly made and seconded, the amendment was carried.

Fred Dickinson moved, W. B. Wilkins seconded the adoption of the proposed amendments to the Constitution. Motion carried.

6. Report of Publications Committee

The FPRS has made considerable progress in developing its publications program during the past year. One important step forward was the addition to the national office staff of our first full-time publications editor, Howard J. Rosenberry.

Two significant changes have been made in the JFPRS. The Journal appeared in printed form for the first time in the November 1952 issue. The technical articles of the Society were combined into one publication when the proceedings of the Milwaukee meeting appeared in December as the Annual Proceedings number of JFPRS. We believe these steps will enhance the reputation of the FPRS and improve its service to the membership. We must all strive for better technical articles in our publications, however, if we are to progress.

The committee recommends a continuation of the policy that *section* papers be edited by a responsible representative of the Society before release to the trade press. However, if the paper is desired only for abstracting or to aid the reporter in accurately covering the section meeting then an extra copy, if available, may be given him directly. We recommend further that papers presented at the annual *national* meeting not be released to the trade press for any printing, other than brief abstracts, unless the article has received an award sponsored by a trade journal. We suggest that the section officers be adequately informed of the procedure to be followed in the treatment of section papers so that they may cooperate effectively with the national publications committee member assigned to cover the region through which the section operates.

We recommend that the preprints of papers to be presented at the annual national meeting be in the hands of members at least two weeks prior to the meeting. Papers not submitted soon enough to meet this deadline should be given out at registration time. It is unfair to an author who submits his article by the deadline set by the program committee to be deprived of the opportunity of having

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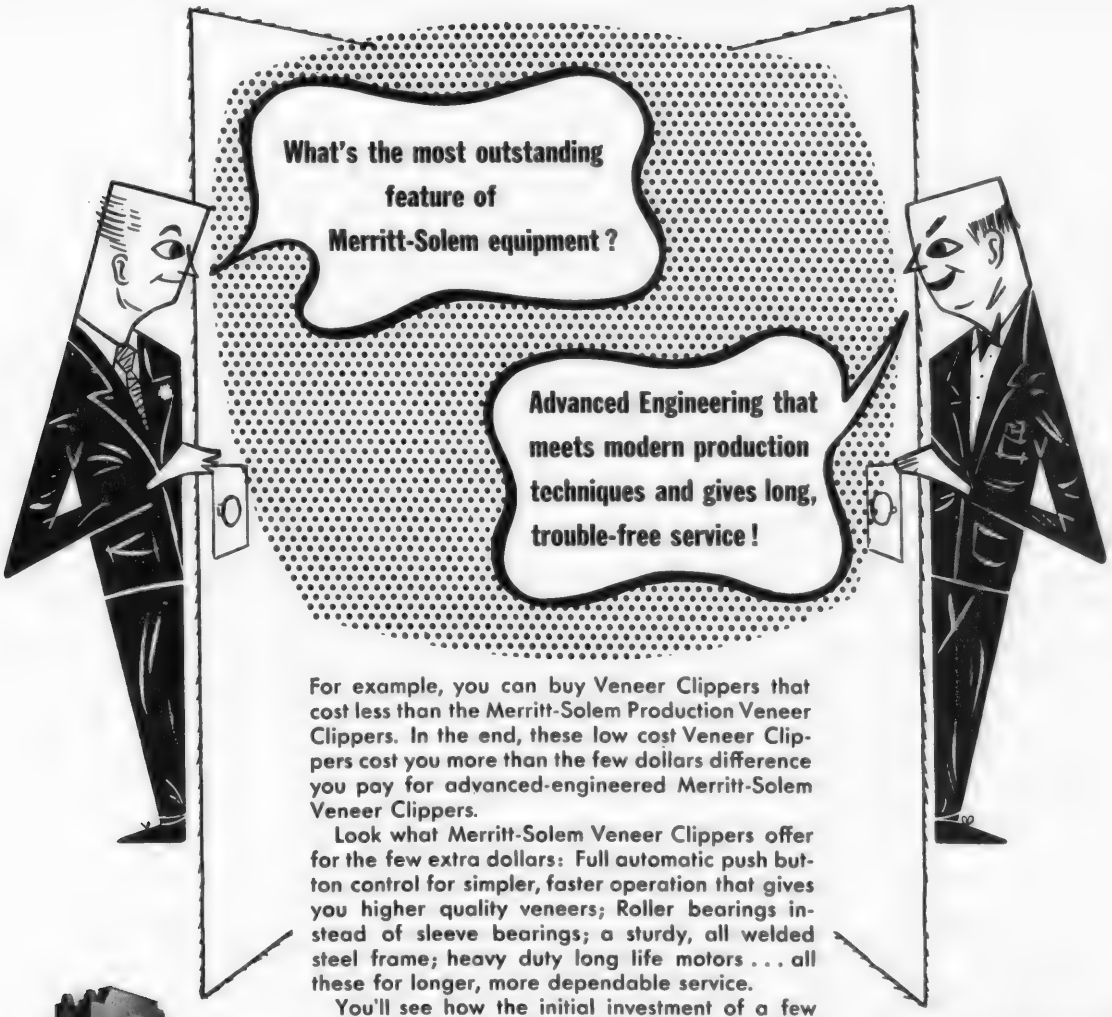
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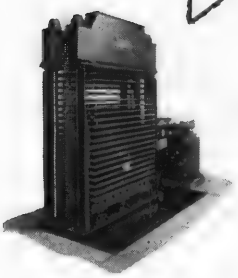

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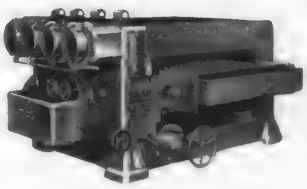

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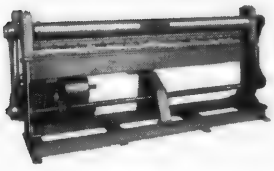

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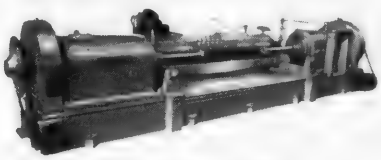

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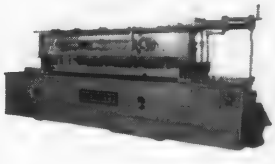

TRAVELING HEAD VENEER JOINTERS

his paper studied in advance of the session so that spirited discussion may ensue. We recommend continuance of the present policy in JFPRS of using abstracts obtained from other selected abstract journals.

We wish to thank the staff of the national office for its continued efforts to improve the standards of our publications. In conclusion, the chairman desires to express his appreciation to the other committeemen for their devoted cooperation in behalf of better publications for FPRS. E. A. Behr, J. S. Bethel, R. A. Cockrell, J. B. Grantham, R. C. Rietz, J. F. Saeman, F. F. Wangaard, I. H. Isenberg, *Chairman.*

7. Report of Subject Matter Committees

General Chairman, Roy M. Carter, reviewed the organization of 13 existing committees. (See individual reports, pages 00–00); and reminded the membership that they, as individuals, are privileged to participate in the work of these committees. He outlined the general responsibilities of the committees as follows:

1. Serve as a point of contact between the subject matter field and the FPRS its sections and members through such media as meetings, publications, etc., as may be available to the Committee through the efforts of the Society.

2. Hold an annual meeting of the Subject Matter Committee to review accomplishments and plan future activities. (This meeting would be in conjunction with the annual FPRS meeting.)

3. Prepare and present an annual report for adoption by the Society and publication as a part of the proceedings of the annual meeting. This report would record pertinent information of significance in the subject matter field of interest to the forest products industry. The initial report of each subject matter committee would be a comprehensive statement defining and recording the status of research and development activities in the subject matter field.

4. Develop such specific material and engage in such activities within the scope of the subject matter field as is considered appropriate by the Committee.

5. Work with annual meeting Program Chairman in planning and development of Technical session program as scheduled by the Executive Board.

8. Report of Membership Committee

In an effort to refine and strengthen the membership activity, a tremendous amount of work was requested and furnished by the National office. This consumed a large portion of the year, and the revised method and approach for getting members can take some credit for the very substantial gain that is shown on the "Report of Net Membership as of June 3, 1953".

First, I would call your attention to the fact we have now passed the 2,400 figure of net members. The figures speak for themselves, but I would like to call your attention to the student membership which shows a decline of 90. The other classifications show a steady increase.

We have prepared and mailed to each National Membership Committee member a complete analysis of membership by kind of business, broken down by states; an analysis by occupation, also by state. From this type of information, each committee member will analyze the actual membership in his section against the potential by business and occupation. Names will be selected as real possibilities for membership from this potential, and they will be approached with a presentation of preprints concerning their particular activity or business. These

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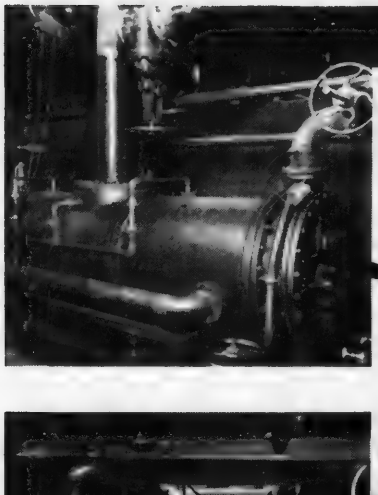

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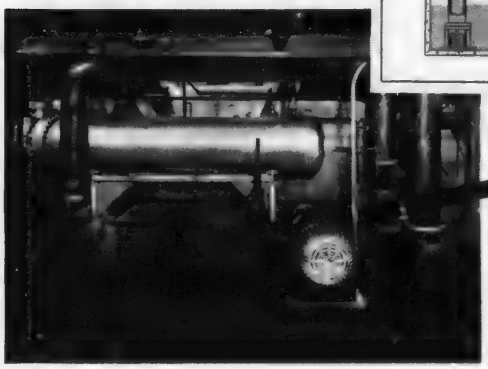

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preprints are available from the National office and will be bound up in complimentary packets, containing literature describing the Society, and a membership blank. A record, copy to the National office, will be kept on the distribution of this material, so the National office will be in a position at all times to institute an immediate follow-up. To achieve this very necessary follow-up action, it is proposed that a part time employee be engaged for the sole purpose of membership activity.

In concluding this report, I would like to thank the section membership chairmen who compose the National Committee, and point out that it is through the efforts of men such as these that the society can point with pride to its achievement of growth from 1261 members on March 31, 1948 to the June 3, 1953 figure of 2350.—L. J. CARR, *Chairman.*

9. Report of Resolutions Committee

(1) In recognition that the success of this Seventh Annual Meeting of the Forest Products Research Society is in a large measure due to the foresight, planning, and diligence of the various responsible committees, and in particular of the Memphis meeting committees,

Be it resolved that the Society hereby acknowledges its appreciation to the chairmen and the members of these committees for their excellent and successful work.

(2) In appreciation of the meritorious services that they have rendered to the Forest Products Research Society during their period in office,

Be it resolved, that the gratitude of the Society be extended to all of our outgoing officers including executive officers, Regional Board Members and Section officers.

(3) In view of the splendid cooperation and services provided by our host Hotel, The Peabody, in helping to make this annual meeting a success,

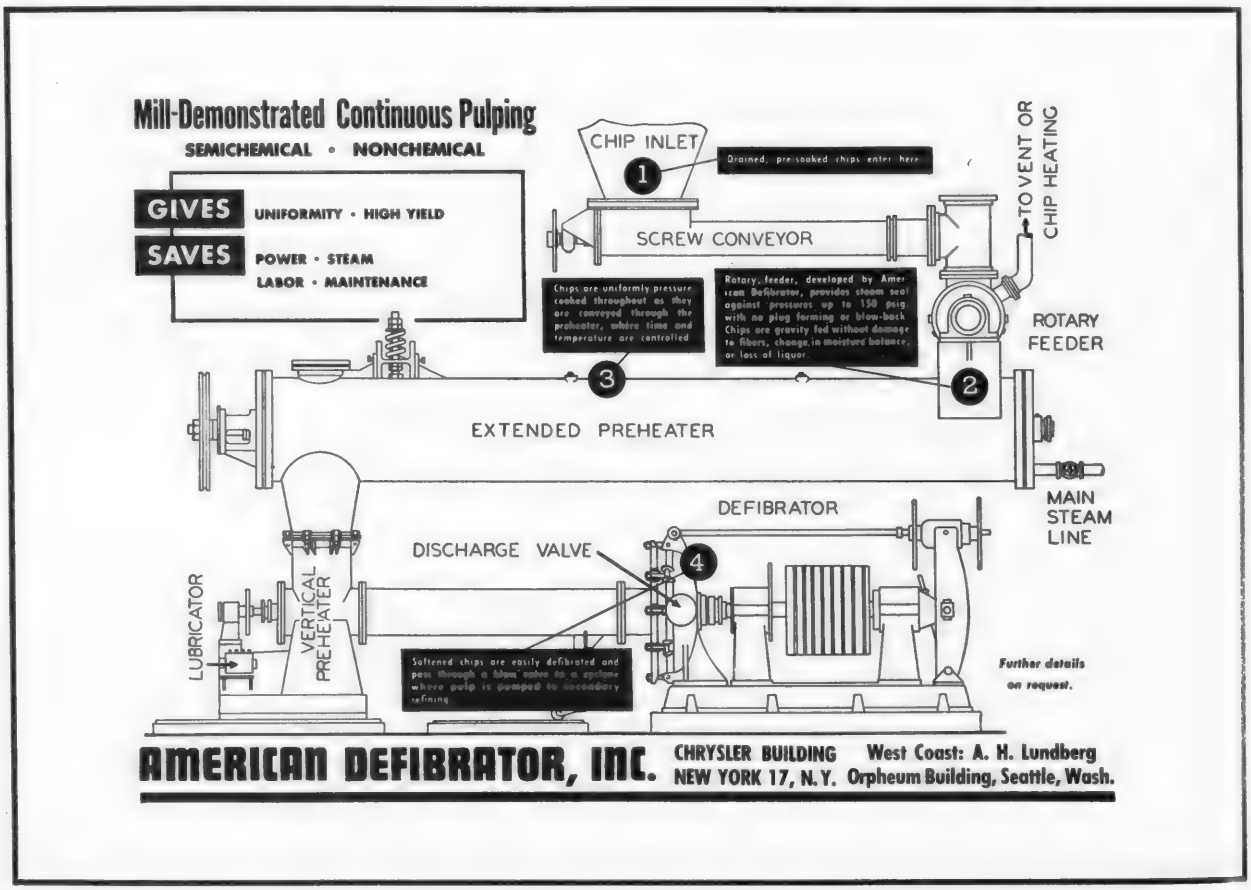
Be it resolved that the appreciation of the Society be extended to the Management and to the entire staff and that a copy of this resolution be forwarded to the Hotel.

(4) The Society records with deep regret the passing during the past year the following members: Douglas K. Bland (killed in action, Korea), Thorwald A. Carlson, A. R. De Burgh, Paul K. Guillow, John Thomas McGee, O. S. Porter, C. L. Thompson, and Dr. Eric Wahforss, and Don L. Quinn.

Be it resolved that this expression of sympathy to the families and friends of these men be included in the permanent records of this meeting and of the Society. (Those assembled observed a moment of silence)—R. H. BESCHER, H. R. EVANS, E. G. LOCKE, *Chairman.*

10. 1954 National Meeting

Pres. Chesley announced that the eighth National Annual Meeting would be held in Grand Rapids, Michigan, May 5, 6, 7, 1954, in cooperation with the "1954 Woodworkers Industry Show" which is being conducted by a separate organization, R. Hiller and A. Stuart Co. Both organizations will cooperate fully on hotel arrangements, meeting room facilities, and timing of various events so that participants will be assured of being able to take in the highlights of both the FPRS meeting, and the Industry Show without conflicting arrangements. The president stated that the Industry Show having the full endorsement of the Association of Woodworking Machinery Manufacturers, in conjunction with the Annual Meeting of the Forest Products Research Society, means that probably FPRS will have the largest attendance of any previous National Meeting with additional thousands in for the Industry Show.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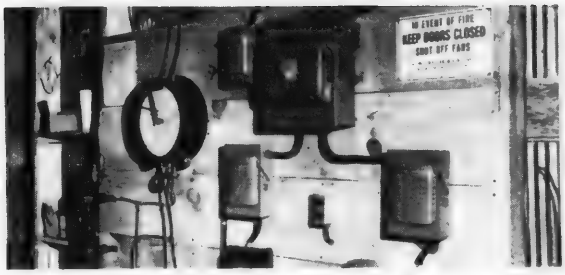

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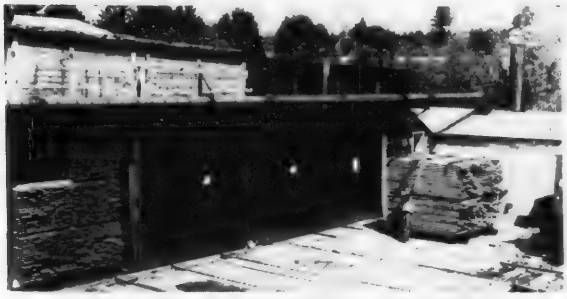

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11. New Business

No new business was presented. President Chesley then publicly thanked his Executive Board, the Section Officers, various Committees, and the entire membership for their support in enabling his administration to write an inspiring chapter in the growth of FPRS.

12. Introduction of New President

Pres. Chesley introduced incoming President Pauley, who was elected to succeed to the presidency at the 1952 National Meeting. He is a charter member of FPRS; served as Northwest Regional Board Member, 1948–51; as general chairman of the 1950 National Meeting and Industry Show at Portland, Oregon; as National Chairman of membership, and of finance; and as National Vice President in 1951.

Professionally, he is the manager of Weyerhaeuser Timber Company's Special Products Division of Tacoma, Washington.

Incoming President R. D. Pauley, after his introduction, paid a glowing tribute to Kenneth Chesley, in these words: "Scientific background, broad knowledge of wood industries' operations and a sincere desire to further forest products research have contributed to the successful formula of our retiring president. Kenneth G. Chesley, Director of Research for the Crossett Lumber Co., Crossett, Ark., is rounding out his seventh year as an officer of this Society and the current year as President.

Since his installation as president of our 2,400 member international organization at the National Meeting at Milwaukee last June the Society has made great progress. A number of active committees have been established. FPRS subject matter committees, made up of specialists in each branch of forest products, such as lumber, plywood, furniture, education, etc., are meeting and corresponding to further interest in their specific fields in Society meetings and affairs.

Other advancements have been in the establishment of a national technical Journal for the industry and expansion to a full time editorial staff. Two new chapters, the Ohio Valley and Eastern Canadian, have been added increasing the total number of active chapters in the U. S. to 13.

Chesley has traveled extensively on Society business throughout the South, East, Midwest and Pacific Northwest. A charter member of FPRS holding membership No. 2 he was one of its founders in 1947. He served as Executive Board member for the South Central Region from 1947 to 1950 and was elected FPRS Vice President in 1950, and President-Elect in 1951. The Society and industry he has served so well owe a great debt of gratitude to his persevering and inspiring leadership."

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13. Adjournment

Meeting adjourned at 12:00 p.m.

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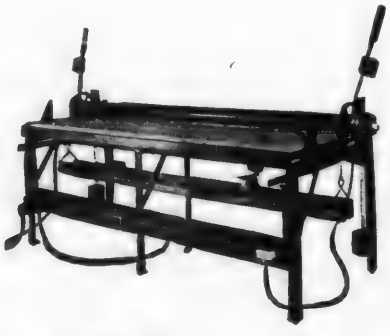

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1953 FPRS Subject Matter Committee Reports

EDUCATION—June 14—Chairman, R. W. Wellwood, University of British Columbia

The first hour was devoted to brief presentation of the following topics: What kind of men should obtain technical training in forest products technology, what can the universities do to encourage the proper men to enter the field of forest products technology, and what can the FPRS do to encourage the proper men to enter the field of forest products technology?

In the following open discussion the following motion was passed: In order to improve the number and quality of students entering the schools for training in forest products it is moved that "the Society sponsor a brochure aimed at acquanting high school students and others of opportunities in technical training in preparation for a career in the forest products industries."

The problem of uniformity in the naming of degrees in forest products and other curricula was discussed and the following motion passed: That "a committee be appointed to study the feasibility of adopting a standard name for graduates of forest products or wood technology curricula." Results of action of the two motions will provide adequate material for discussion at the 1954 open meeting. No technical session is suggested.

During the year the committee set up rules for the Wood Award competition and arranged for the judging of the papers submitted.

CHEMICAL UTILIZATION—June 15—Chairman, R. C. Sproull, Herty Foundation Laboratory

The chairman set forth the following purposes of the meeting: (1) Recommend to FPRS Executive Board the tenure for the Chemical Utilization Subject Committee Chairman and how to select such officer, (2) Recommend to FPRS Executive Board the length of service for committee members, and (3) Suggest objectives for the Committee.

It was voted that the subject committee recommend to the Executive Board that continuity is highly desirable and that this continuity be accomplished by an annual election of officers; namely, vice-chairman, and secretary. The officers can be reelected to the same position. The officers will be elected at the annual meeting and the encumbent officers will present a name in nomination for the office of secretary and will provide opportunity for other nominations at the annual election. It was voted that R. C. Sproull serve as chairman for the next two years and that at the next annual meeting a vice-chairman and secretary be elected for one year terms.

It was voted to recommend to the Executive Board that membership of the committee be appointed annually with reappointment to the committee to be dependent upon active participation in committee affairs.

The following objectives have been established for the Chemical Utilization of Wood Subject Matter Committee: (1) Render all possible assistance in preparing technical sessions on Chemical Utilization for the national meeting, (2) Encourage and assist in scheduling chemical utilization papers at FPRS section meetings, (3) Work with and coordinate FPRS chemical utilization activities with other technical organizations having interest in this field, (4) Undertake cataloging of current research in chemical utilization of wood, and (5) provide all possible aid to prompt commercialization of developments in chemical utilization of wood.

An effort will be made to have a number of representative papers submitted to the Chairman by February 1954. These papers will be assigned to a review board by the Chairman for selection of five to be given at the next national meeting. All others submitted will be submitted for publication in the FPRS Journal.

GLUES AND GLUING—June 15—Chairman, Alan Marra, University of Michigan

Alan Marra, Chairman, introduced the general aims of the committee, namely to present summaries of results of current technical research on gluing wood and to discuss new and improved methods of research in this field.

Professor James Bethel, of North Carolina State College, gave a brief summary of new work being undertaken under his direction to investigate the possible effects of high temperatures used in drying certain hardwood veneers and their subsequent gluability with several different flour-extended urea-resin glues.

John Yavorsky, of New York State College of Forestry, then discussed probable mechanical stresses that caused in edge-glued lumber panels under moisture content changes and suggested that much of such glue-joint failures were due to cleavage on the glue line. He then described studies at Syracuse to develop a simple cleavage-type test for glue joints with particular emphasis on investigations of the stress-strain relationships in the wood adjacent to the glue during such cleavage. This work is just getting well started.

Mr. Edward Hinken of the University of Michigan, reported on his interesting investigation of the effect of glueline thickness on the tensile strength of the joint using an ingenious gap-type specimen in which a known positive, hydrostatic pressure was applied to the glueline during curing. This permits a distinction between external clamping pressure and the actual bonding pressure. Data were presented for several types of glues to illustrate the effect of glueline thickness, and bonding pressure on initial tensile strength and to show the effect of aging of urea-resin gluelines of various thicknesses on the tensile strength.

George Marra, of Washington State College, discussed studies underway in his laboratory to develop an improved glue-joint test specimen by modifications of the conventional plywood shear specimen and discussed the need for further study of the use of modern statistical techniques to improve sampling for glue-joint tests.

Dr. R. F. Blomquist, of the U. S. Forest Products Laboratory discussed the various factors that are believed to cause deterioration of glue joints in different types of service and then outlined the problems in adequately simulating these effects in durability tests under controlled and partially controlled conditions in order to more accurately evaluate the durability characteristics of the various woodworking glues. Currently used methods for evaluation of durability of glues were discussed and the need for well-coordinated tests of actual glued wood articles in actual service was pointed out.

Alan Marra requested that suggestion on the scope of future activities of the Committee be sent to him and several good ones were immediately offered.

LOGGING AND MILLING—June 15—Temporary Chairman, Roswell D. Carpenter

Mr. Roswell D. Carpenter presided over the meeting as temporary chairman. Mr. Kenneth C. Compton, College of Forestry, Syracuse was nominated as secretary of the group.

Ten members each of the Logging committee and Sawmilling committee were presented.

The meeting was organizational in nature, outlining the objectives, scope, and duties of this committee, which were adopted:

(1) To provide advice and guidance to the officers and members of the society on the technical aspects of logging and milling relating to conducting the affairs of the society.

(2) To assist program committees by suggesting speakers and topics, and by otherwise aiding in the development of technical programs.

(3) To sponsor and encourage meetings of experts engaged in or interested in the subject of logging, and milling for informal discussion of progress, methods, and problems.

(4) To forward the objectives of the Forest Products Research Society as they relate to logging milling procedures by coordinating the activities of Society members interested in logging and milling by formulating plans of action, and by otherwise encouraging activity in this technical field.

(5) To assist and participate, wherever possible, in conferences, demonstrations, and programs conducted by other agencies and report all such activities to FPRS through this Committee in regions where you are located.

(6) To direct attention to the abstracting committee to articles and reports in the fields of logging and milling and to submit abstracts to this committee as occasion indicates.

(7) To inform Regional and National Trade associations in these fields, through the National Secretary's office, of this committee's existence, objectives, and desire to cooperate in their activities in the fields of logging and milling.

(8) To work in close cooperation with other subject matter committees of the Forest Products Research Society, such as Wood Drying and Machining where interests of these committees are in common.

(9) To select sub-committees within this Committee for attention to particular subjects. Such sub-committees to include interested individuals from outside this Committee whenever desirable.

(10) The interests of the Logging Section of this committee shall include the necessary coordination between logging and forest management.

(11) The various subjects of logging and milling will be reviewed by the combined Logging and Sawmilling Committee, since many of the subjects are of common interest to these two groups.

Chairman Carpenter acquainted the Committee with the efforts of the American Standards Association, Inc. in the field of "standardization of sawmill performance" to reduce waste.

A motion was adopted recommending that the Forest Products Research Society act in the capacity of co-sponsor in the study of Sawmill Standardiza-

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tion in cooperation with the following organizations:

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A sub-committee was appointed to review the subject, cooperate with the above organizations concerning the subject and report back to this Logging and Sawmilling Committee their findings.

A sub-committee was appointed to review the subject of a "standardized unit of measure for chipped wood."

QUALITY CONTROL—June 15—Chairman, Charles Latimer, Nickey Brothers

The minutes of the 1952 committee meeting at Milwaukee were read and approved. This approval included the adoption of the following definition for quality control: "Quality control is the maintenance of quality at the desired levels by predicting future quality based on an analysis of recent quality performance."

The chairman announced that the Society had established a policy ruling out the establishment of standards and test techniques as a committee or society function.

The committee voted unanimously to request that a session on Quality Control be placed on the agenda of the 1954 Annual Meeting at Grand Rapids, Michigan, with the stipulation that the session be held concurrently with either the sessions on Logging and Milling, Packaging, or Chemical Utilization, avoiding those other sessions where there is a wide over-lapping of interest. The chairman appointed Richard C. Calahan to obtain a keynote speaker for the 1954 session on Quality Control, should such a session be approved. The committee voted unanimously against circulation of a questionnaire on quality control.

The committee discussed ways and means to circulate and publish short papers dealing with specific applications on quality control in the wood using industries. It was agreed that six copies of such papers should be submitted to the committee chairman and that these could be circulated to interested parties. Further, it was agreed to request publication in the Journal of the FPRS of such papers as are deemed to be of sufficient general interest.

WOOD COMPOSITION BOARD—June 15—Chairman, George G. Marra, Washington State College

The meeting was opened with a statement regarding committee membership and functions. It was emphasized that the principal function of the committee is to keep the Society informed of progress in the field of composition products and to assist the program chairman in preparing for the national meetings. The committee is therefore a working committee and members devote time and effort to the job when called upon. The membership of the committee is not fixed and anyone who wishes to actively contribute his knowledge to the work of the committee should make his desires known to the chairman. It was pointed out that the committee can operate most effectively with representation from all segments of the industry.

The present plan is to hold an open committee at each FPRS national meeting. Everyone is invited to attend these meetings and any suggestions or comments will be gratefully received.

Discussion of desirability of holding another technical session at the 1954 national meeting resulted in unanimous approval by all present. It was agreed that the next technical

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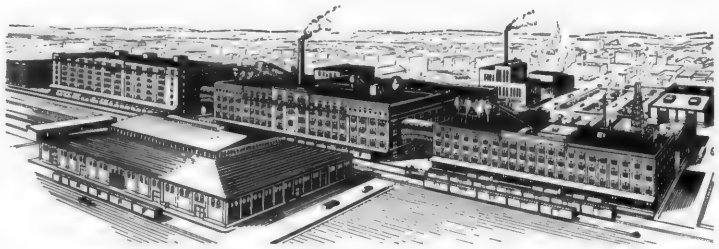

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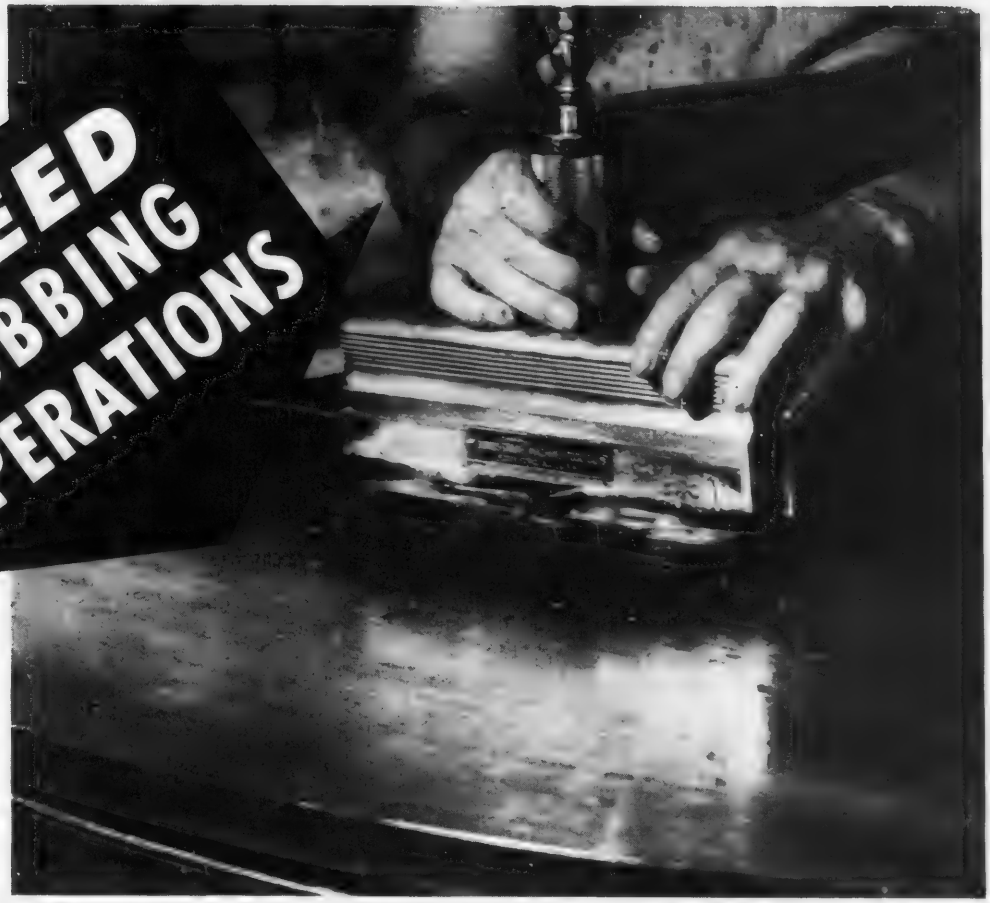

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session be general in nature, rather than follow a theme. In regard to the term of each committeeman, the majority favored a 3-year term with option of re-appointment. The committee voted in favor of electing its own chairman each year.

It was recommended that the composition of the committee consist of nine men representing hardboard, chipcore, softboard, molded products, resin manufacturers, equipment manufacturers, consumers and fabricators, and sales organizations.

It was suggested that the national office circularize the membership in order to compile a list of members who wish to serve on particular committees. Committee vacancies could then be filled from this list with greater likelihood of acquiring willing and energetic new blood on committees when the need arises.

Since committee meetings and sessions are now being held concurrently it is inevitable that some conflict of interest should develop. As far as composition board is concerned, it was felt that these conflicts might be minimized if program planners were advised to avoid when possible scheduling concurrent sessions involving Glues and Gluing, Chemical Utilization, and Composition. Board.

WOOD DRYING—June 15—Temporary Chairman, Fred Dickinson, University of Michigan

It was decided that if the chairman in office was willing to serve an indefinite number of terms he should be allowed to do so. A new chairman should be appointed by the president. The length of a committee member's term was considered and it was decided that he could stay on as long as he wished. Any new interested members would be welcomed till at such time the committee got too large; then some other arrangement could be made.

It was suggested that a copy of the Wood Drying News–Digest which is distributed to members of the various dry kiln clubs through the secretaries of these groups be sent to each member of FPRS and also to trade papers. Good papers or abstracts from the kiln club meetings should be sent to Rietz for distribution in this or some other manner to the kiln clubs.

The subject of a technical session at Grand Rapids next year seems very probable; a series of papers are in the making and we feel will be available by then. It was also decided that a half-day session previous to the opening of the Grand Rapids forum should be considered by all committee members. It was also considered a must that Ray Rietz should get together with committee members in the section in which he is traveling to consolidate ideas throughout the year. If a committee man has any troubles to hash out he should bring all information to the half-day meeting before the next technical session.

It was also suggested that committee members send to Ray Rietz suggestions for research suitable for either laboratory or field study and that such suggestions be made available to all committee members and dry kiln clubs. Can write Bill Pratt for sample project sheet as an example of how to prepare a project sheet.

WOOD FINISHING—June 15—Chairman, B. E. Clatworthy, Radio Corp. of America

The meeting was opened by Chairman Clatworthy who reviewed the minutes of the last meeting and reported on the response to the questionnaire sent out to furniture manufacturers.

The term of the wood finishing committee chairman was agreed upon as not less than two years and not more than three. It was agreed that the chairman should be one who had

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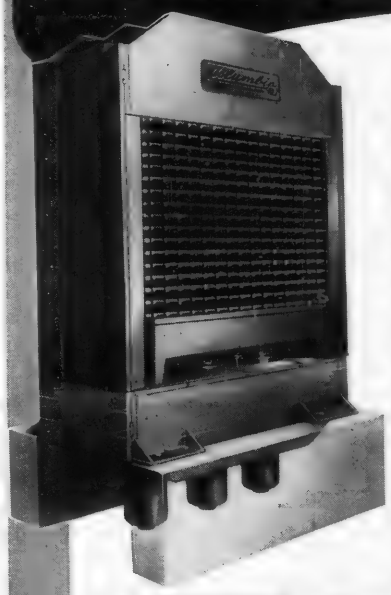

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had the opportunity of observing at least one year's work of the previous chairman.

The committee voted that there should be a finishing session in 1954. There will be at least three papers on furniture finishing at the Grand Rapids meeting.

WOOD MACHINING AND EQUIPMENT—June 15—Chairman, L. A. Patronsky

The minutes of the last meeting in Milwaukee were read and approved. As the members at the Milwaukee meeting had appointed an active committee, Mr. Patronsky brought up the subject of make-up of this committee both in regard to duties, numbers, and the manner of appointment. Mr. Stanley suggested that the General Committee Meeting be open to all interested parties for discussion and comments but that the active committee itself be limited to a few members whose responsibility would be the carrying out of the recommendations brought out at the General Committee meeting.

Mr. Patronsky asked Mr. Carter how the present committee was selected. Mr. Carter said the committee and the chairman had been appointed by the President of the Forest Products Research Society but it was the desire of the Executive Board that the committees should recommend to the President their new members as well as their recommendation for chairman.

It was also voted that the active committee be made up of eight (8) members and a chairman and that two (2) new members be appointed by the chairman each year to replace those who have served previously.

It was also voted that the present chairman appoint two (2) new members to supplement the previous six-man committee and that rotation and recommendation for new chairman be started after the present year.

Mr. Patronsky reviewed the work of last year's committee in arranging for papers for the present meeting in Memphis and emphasized the importance of that contribution by the Committee. The 1954 Annual F.P.R.S. Meeting will be a combination Wood Working Show and Meeting. It is equally important that a good woodworking machine program be presented.

The preliminary work on Nomenclature of Saws and Knives was presented. After some discussion, it was decided not to try to follow A.S.A. Metal Cutting practice for terms but keep to wood terminology where possible and use existing wood literature as a guide. The Saw and Knife forms as submitted were to be reviewed by two sub-committees. Mr. R. Reynolds for the Knife Group and Mr. N. C. Bye for the Saw Group will submit to Mr. Patronsky their sub-committee recommendations which will be reviewed by the general committee before releasing for trade comments.

WOOD PRESERVATION—June 15—Acting Chairman, W. N. Darwin, TVA

After heavy discussion a motion was moved, seconded, and carried that a subject matter committee on wood preservation be formed and that such committee prepare annual reports. Another motion was carried that Acting Chairman Darwin and Acting Secretary Lehrbas remain in office until the official committee is formed. The function of the newly created committee is to: (1) Keep before the FPRS developments in the field of wood preservation of interest to the society, (2) Assist members in making contacts relating to sources of technical information on wood preservation, (3) Serve as liaison for the Society with the American Wood Preservers Association and others, (4) Call attention to developments in wood preser-

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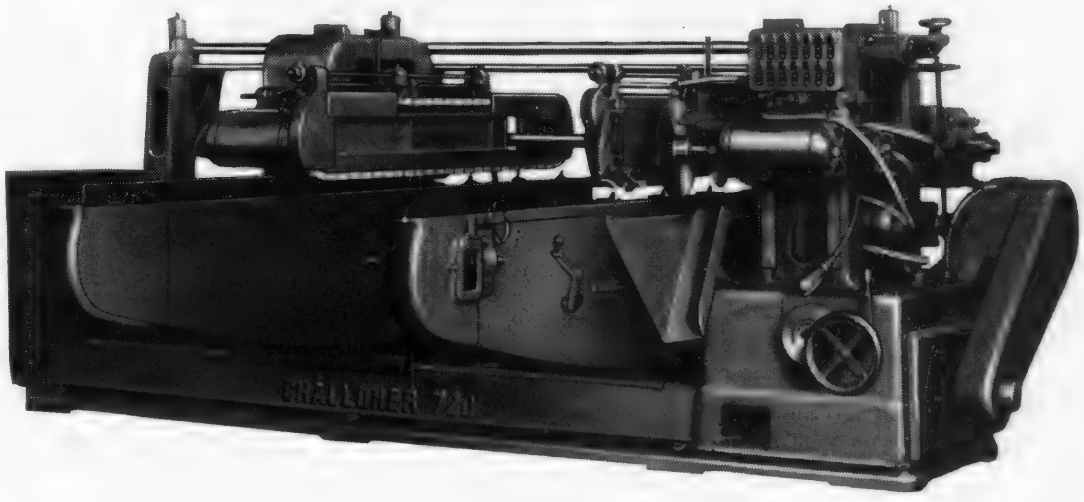

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vation to the Society, (5) Coordinate with committees from other agencies such as the BPIS&AE, Bureau of Entomology & Plant Quarantine, etc., and (6) Advise and assist in developing programs in the field of wood preservation for the National and Section meeting of the FPRS.

PACKAGING—June 16—Chairman, Earl R. Stivers, Package Research Laboratory

Mr. Stivers opened the meeting with observations on the economic importance of packaging to industry and to consumers. Billions of dollars are wasted because of loss in production, labor, and distribution of merchandise, due to faulty packaging. Enormous losses in material were sustained during World War II due to inadequate packaging. As a result of this, training programs at the Forest Products Laboratory were initiated and the various branches of the military services set up their own laboratories. Leading packaging men were called to assist, and independent laboratories asked to solve specific packaging problems.

In consequence of this wartime activity, packaging came to be recognized as an important branch of industry and the military. Packaging men today are considered part of management, and problems in packaging are given as important consideration as production.

Where does FPRS fit into the picture? It should avoid duplication of effort, but could play an important part in promoting materials derived from wood for packaging, encouraging research and education and stimulating industry to use wood more efficiently and economically on its own merits.

What should be the functions of this committee? It could encourage papers and technical sessions on packaging, disseminate information and educate management to the importance of packaging. It was proposed that the present officers of the committee, E. R. Stivers, Chairman, and A. J. Panshin, secretary, be continued.

Take an active part in FPRS. Join Subject Matter Committees that cover your field of interest. Attend Section and National meetings. Contribute the benefits of your knowledge and experience through presentation of papers and by taking part in discussion. Help the industry grow through FPRS. As the industry grows, so will you.

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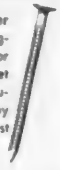

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(Continued from page 5)

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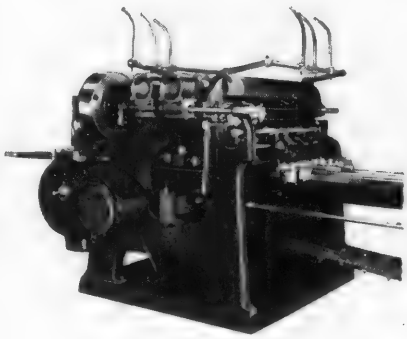

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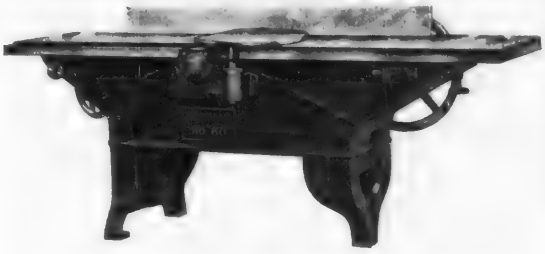

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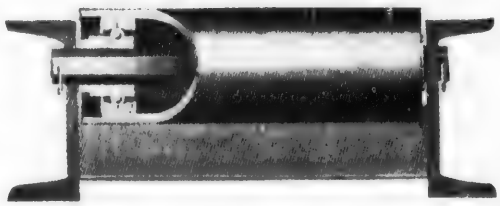

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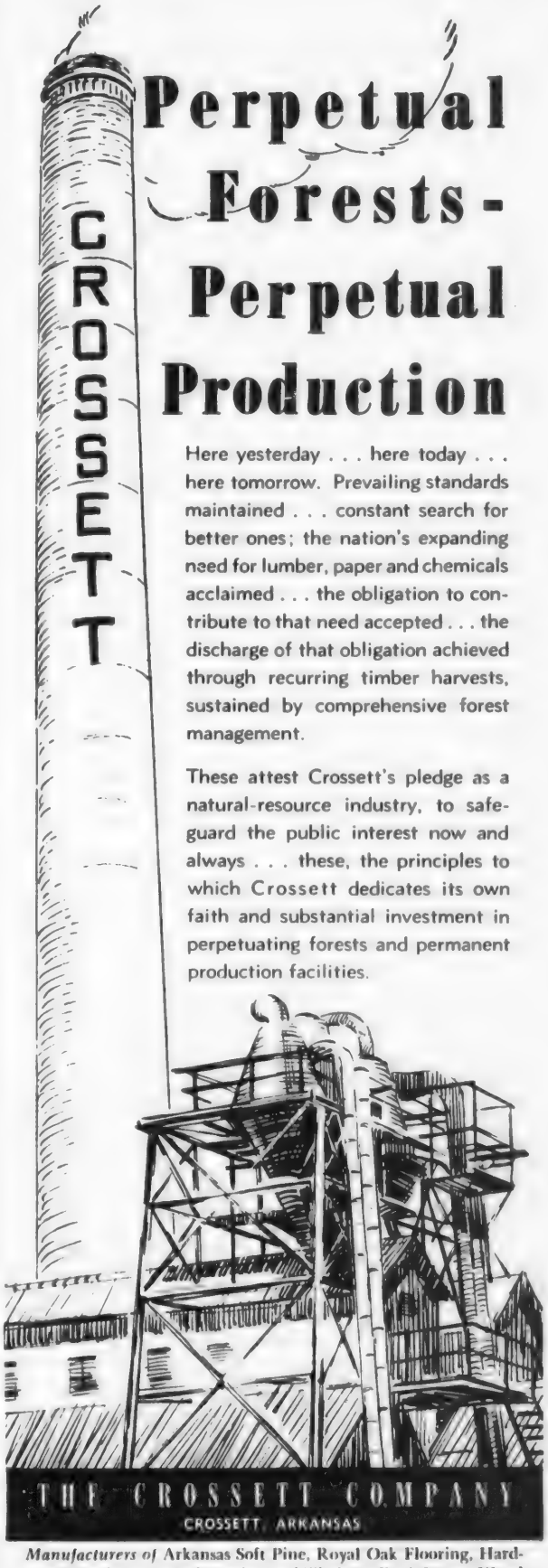

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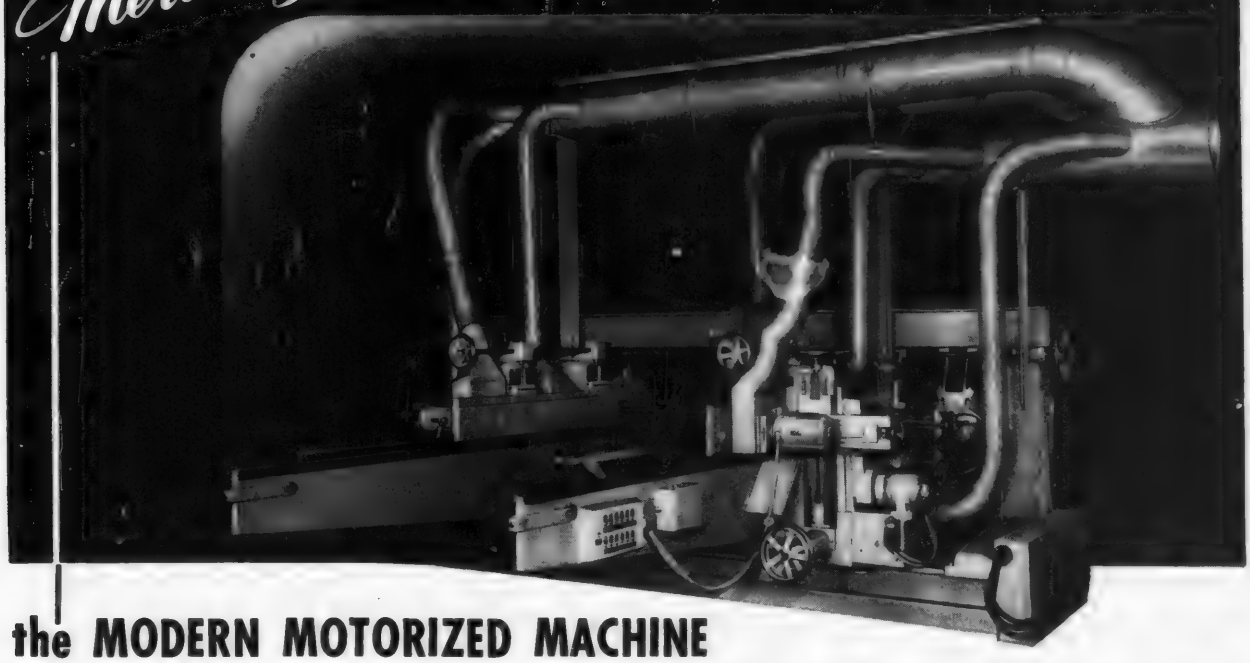

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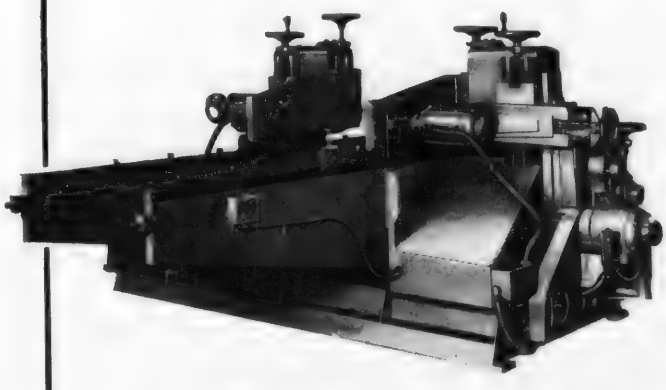

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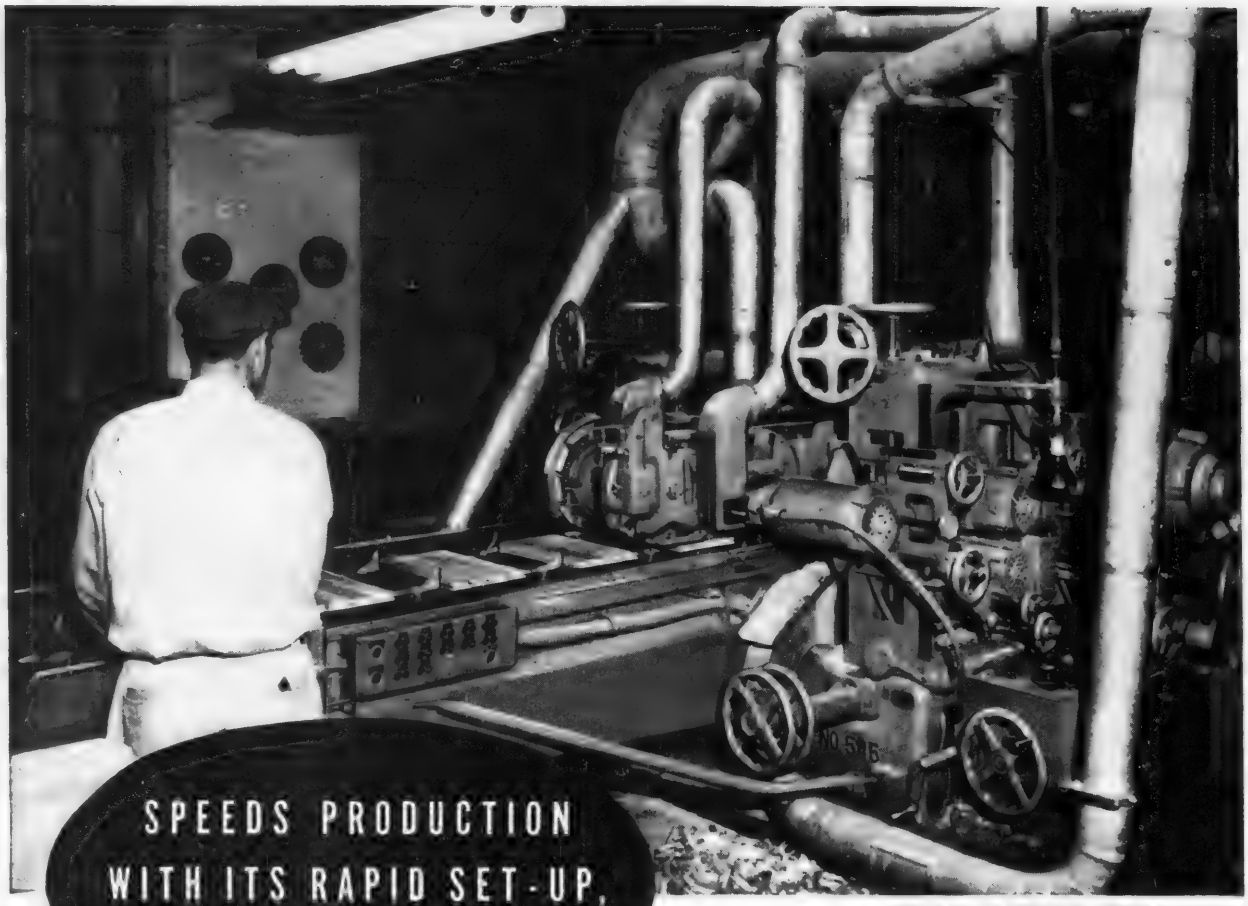

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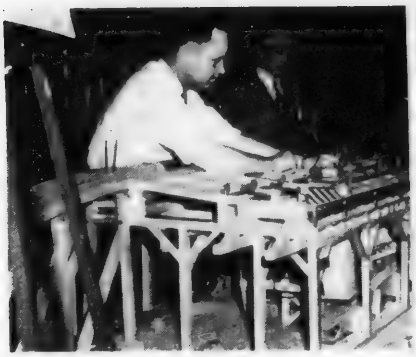

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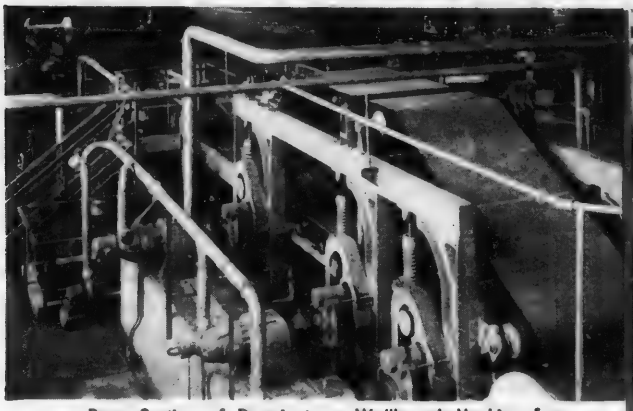
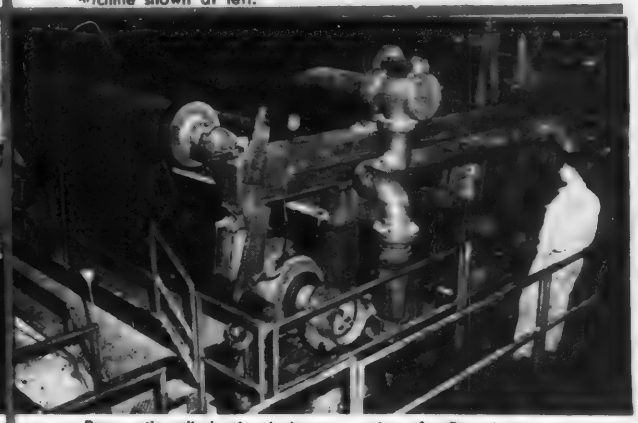


Press Section of Downingtown Wallboard Machine for making hardboard at Oregon Lumber Co.

Head box and Fourdrinier type forming section of the machine shown at left.

Cantilevered press section of a new wallboard machine making either hard or insulating board.



Pneumatic cylinder loaded press section of a Downingtown Wallboard Machine showing two suction press rolls.

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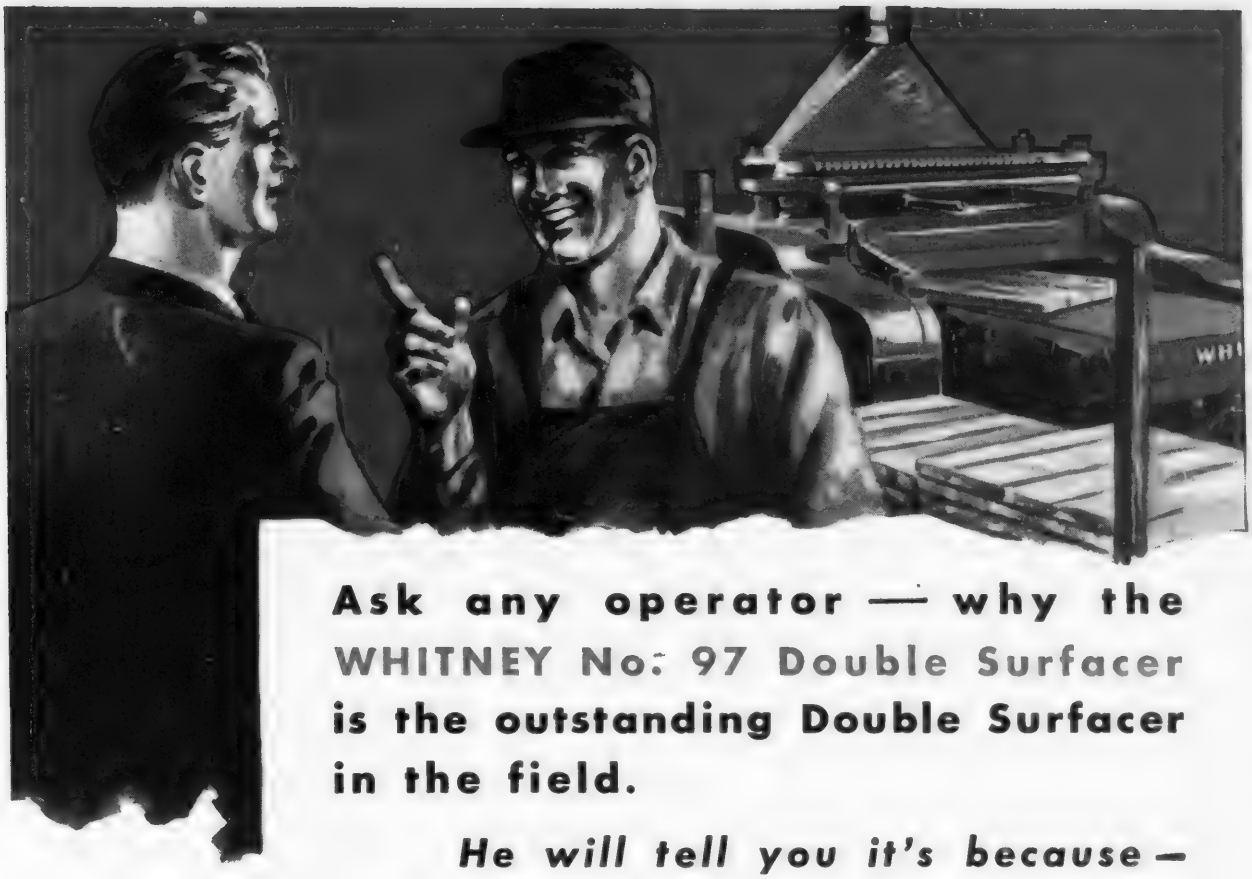

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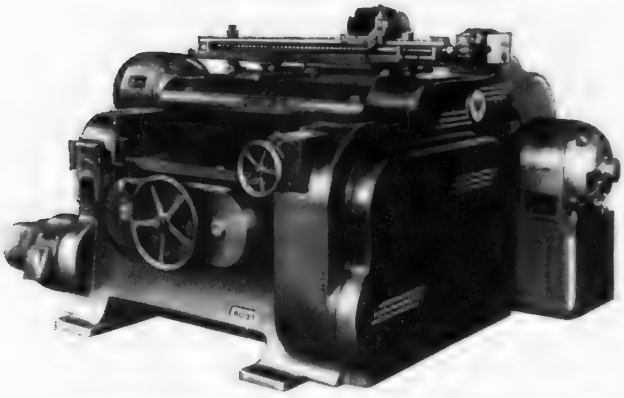

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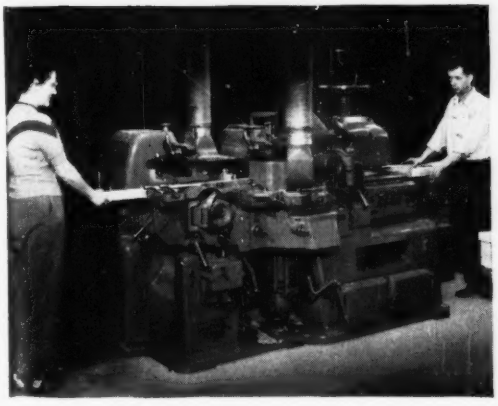

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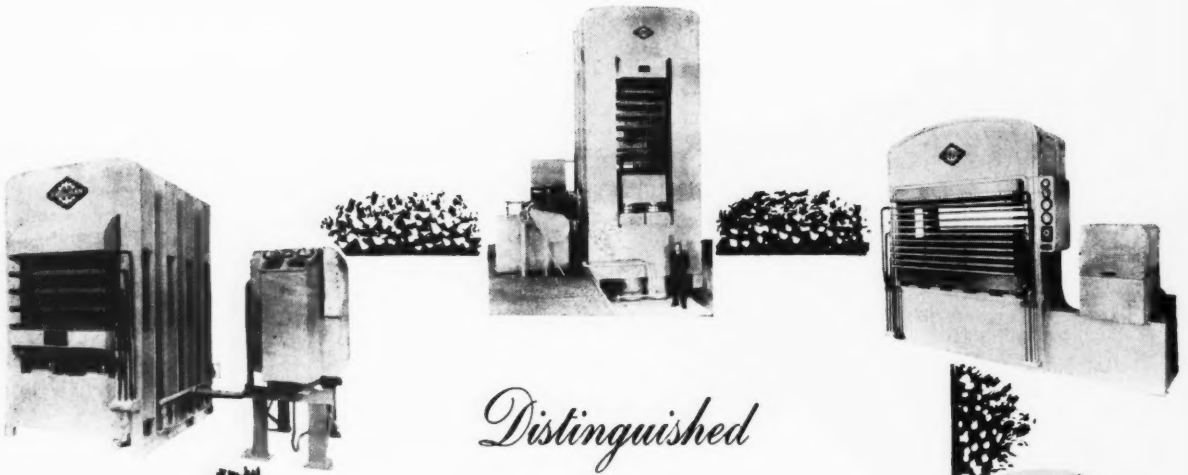

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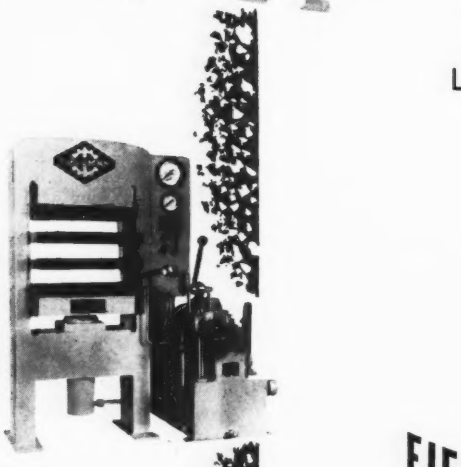

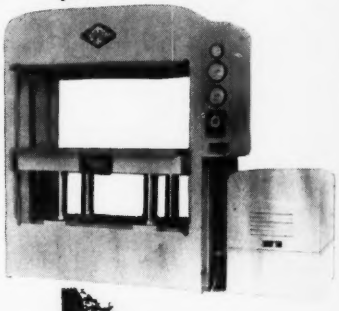

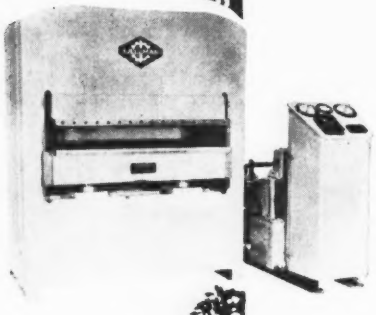

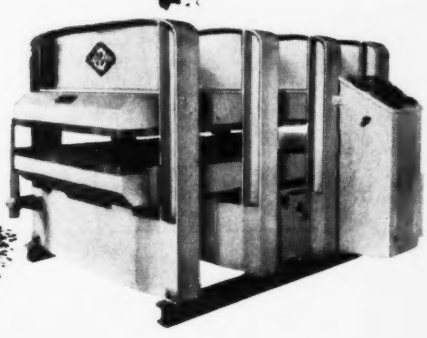

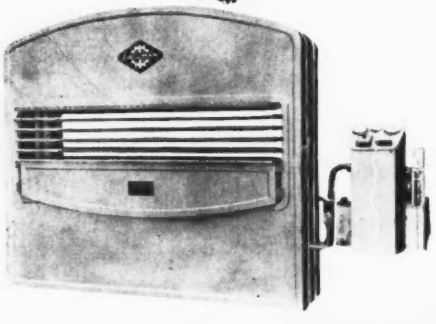

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